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Determinants of noise annoyance in teachers from schools with different classroom reverberation times

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ABSTRACT

A high proportion of school teachers report that they are disturbed by noise during teaching. The aim of the study was therefore to identify determinants of self-reported noise exposure and disturbance attributed to noise among secondary school teachers ($n = 419$) in 10 schools in Copenhagen, Denmark. The schools were selected to show contrasts in classroom reverberation times (RT), and were classified as "Short RT" (3 schools, mean RT 0.41–0.45 s), "Medium RT" (3 schools, mean RT 0.51–0.55 s) and "Long RT" (4 schools, mean RT 0.62–0.73 s). Significant determinants of self-reported noise exposure were a high number of children in the class, young age of the children, and low teacher seniority. "Long RT" classification was of borderline significance. Significant determinants of disturbance attributed to noise from children in the class were teacher seniority and "Long RT" acoustic classification of the school. The associations between work characteristics and noise disturbance measures were attenuated by low self-rated work capacity, suggesting that the consequences of noise and poor acoustics may not be limited to disturbance attributed to noise, but may have a wide negative impact on the perceived working environment.

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1. Introduction

School teaching is a knowledge transfer activity that entails speech communication and a relatively high cognitive workload, both of which are critically dependent on high signal-to-noise levels and good acoustical conditions (Hughes & Jones, 2003; Kjellberg, 2004). From this perspective it is alarming that the prevalence of noise problems is high among school teachers. For example, in the Danish Work Environment Cohort Study (DWECS) 2005 survey, 71% of the teachers reported that they were exposed to loud noise for at least ¼ of the working hours, which is considerably higher than the proportion of 32% among Danish employees on average. That voice problems are also more prevalent in teachers than in many other occupations (Smith, Lemke, Taylor, Kirchner, & Hoffman, 1998) further underscore that the acoustical working environment in classrooms can be quite demanding (Pekkarinen & Viljanen, 1991). Despite this knowledge it is clear that the potential consequences of noise and poor acoustical working conditions on the physical and mental health of teachers have not been sufficiently studied.

Annoyance is the most direct reaction to work-related noise (Kjellberg, 1990). Known contributing factors to noise annoyance encompass both physical characteristics of the noise such as the sound level and tonal components, as well as non-sound factors such as gender, hearing status, the task engaged in, predictability of the sound etc. (Kjellberg, 1990; Kjellberg, Landstrom, Tesarz, Soderberg, & Åkerlund, 1996; Landström, Åkerlund, Kjellberg, & Tesarz, 1995). However, it is not known to what extent these determinants also matter to school teachers, or indeed which sound sources causes most annoyance.

Among the potential determinants of noise annoyance is poor classroom acoustics. Among the parameters used to characterize classroom acoustics, reverberation time (RT) has received particular attention because of the central role it has in determining the role of reflected speech sounds. Reflected speech sounds that arrive shortly (<50 ms) after the direct sounds serve to amplify the direct speech sounds, while reflected speech sounds that arrive later tend to mask the direct speech sounds. Not only does this make the speech more difficult to comprehend, it also impairs memory consolidation of what is heard, which is a consequence that is highly relevant considering the purpose of teaching (Kjellberg, 2004; Ljung & Kjellberg, 2009; Ljung, Sörqvist, Kjellberg, & Green, 2009). Moreover, when there are multiple talkers in the same room (a situation that often happens in the classroom during group

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work, for example), reflected speech sounds may contribute to the background noise. This too, will impair memory consolidation (Kjellberg, Ljung, & Hallman, 2008), and it will also make the talkers to raise their voice levels (Nijs, Saher, & den Ouden, 2008).

The acoustic environment is not the only workplace characteristic that may determine noise annoyance among teachers. The number of children in the class may contribute to noise annoyance, because the number of sound sources (speech, furniture noise) increases with the number of children. Furthermore, the teachers' classroom management and pedagogical skills may also be reflected in the perceived disturbance level. Hence, the disturbance as perceived by the teacher may be lower if the teacher has more experience. Another workplace factor is working time length which has been observed to be associated with noise annoyance (Banbury & Berry, 2005; Kjellberg et al., 1996). Possibly, long working days may lead to more fatigue and a higher susceptibility to disturbance.

The workplace characteristics mentioned above can be considered "objective" in the sense that they are independent of personal evaluations, and because they can, at least in principle, be verified and assigned a definite actual value (Wikman, 2006). Noise annoyance may also be influenced by a number of subjective psychosocial factors (Guski, 1999). For example, it is conceivable that complaints about workplace noise reflect "personality" or a general attitude to the workplace. In this case, noise annoyance is expected to correlate with other complaints related to the working environment. A general negative perception of the working environment could therefore be an independent cause of noise annoyance, but since noise exposure may also contribute to the negative perception then noise exposure may also be an intermediate variable linking objective work characteristics to noise annoyance.

The aim of the present study was to evaluate the mutual interplay of objective work characteristics and evaluations of the physical and psychological working environment with regard to noise annoyance in school teachers. In the study we aim at answering the following questions: First, which noise sources are rated as the most disturbing by the teachers? Second, which work-related objective factors are significant determinants of a high degree of noise annoyance? Third, since it is of interest to know to which degree a general negative perception of the working environment influences noise annoyance, do subjective evaluations of the physical and psychological work environment attenuate the associations between objective work characteristics and noise annoyance? Based on the reasoning presented above, our main hypotheses were that annoyance is positively associated with low age of the children, high number of children in the class, long classroom reverberation time, long working time and lack of experience as a teacher. Furthermore, we expect that negative workplace evaluations reduce the associations between objective work characteristics and noise annoyance.

2. Methods

2.1. Identification of the schools included in the study

Ten schools in the City of Copenhagen were invited to participate in the study. Of the 55 eligible schools, 25 schools were inspected and screened for classroom RT between September 2008 and May 2009 (Fig. 1). The inclusion criteria for acoustical screening was (a) the absence of current plans of renovation of regular classrooms and (b) a high response rate (at least 50%) in a recent questionnaire survey conducted by the City of Copenhagen. The latter criterion was used in order to increase the likelihood of a high response rate in this study. In each school regular classrooms were inspected and the acoustical quality of the room determined by two experts (PMN/SPL). The reverberation time was the primary determinant, and the classrooms were classified as "Low", "Medium" or "High".

Among the 25 schools screened for classroom acoustics, RT measurements were performed in 38 classrooms in 13 schools. The concordance between RT measurements and the RT classification made by the two experts is shown in Fig. 2. The results indicate that the RT classification assigned to the schools that participated in the study reflects an underlying gradient in RT.

Based on the classification of classrooms and measurements (where available), each school received one of three possible classifications, designated "Short RT" (schools where most of the classrooms are of short reverberation time), "Medium RT" (most of the classrooms are of medium reverberation time) or "Long RT" (most of the classrooms are of long reverberation time). From the group of 25 schools, we invited all schools that did not show a large variation in acoustical conditions within the school (i.e. many classrooms with very contrasting reverberation times) and were not engaged in reorganization (i.e. mergers, reconstructions etc.). Ten schools were eligible and all accepted the invitation to participate in the study. The final list of 10 schools included 3 schools classified as "Short RT", 3 schools as "Medium RT" and 4 schools as "Long RT" (Table 1). The teachers in the schools were not informed about the acoustic classification assigned to their school.

2.2. Measurement of reverberation time

The measurements of reverberation time were performed by impulse excitation and reverse integration of the impulse response, and were based on assessments of T_{30} 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. All the classrooms were regular square rooms with a volume between 200 m^3 and 320 m^3. The classification of the classrooms was based the average impulse response in the octave bands from 125 Hz to 4000 Hz.

2.3. Participants

Lists of the teaching staff were obtained from the schools. Invitations to respond to an internet-based questionnaire were sent to the teachers by e-mail ($n = 378$) or letter ($n = 41$) on September 2, 2009. Questionnaire responses were accepted until September 21st. Out of 419 potential respondents from 10 schools, 283 (67.5%) filled in a questionnaire on health, disturbance by noise, and other work-related items. Of the respondents, 89 were men (31%) and 194 women (69%), mean age (range) was 45 (21–65) years (men) and 45 (25–66) years (women), respectively. The response rate ranged from 43 to 89% from different schools (Table 1). There were no indications that the response rate depended on the RT classification of the school.

2.4. Outcome measures

Outcome measures were 2 items assessing self-reported exposure to noise that disturbs teaching, and the degree of disturbance attributed to noise from different sources (traffic, children in other classes or in the corridors, children in the class, and ventilation and other machinery in the school). Table 1 presents the wordings of the items and the response categories.

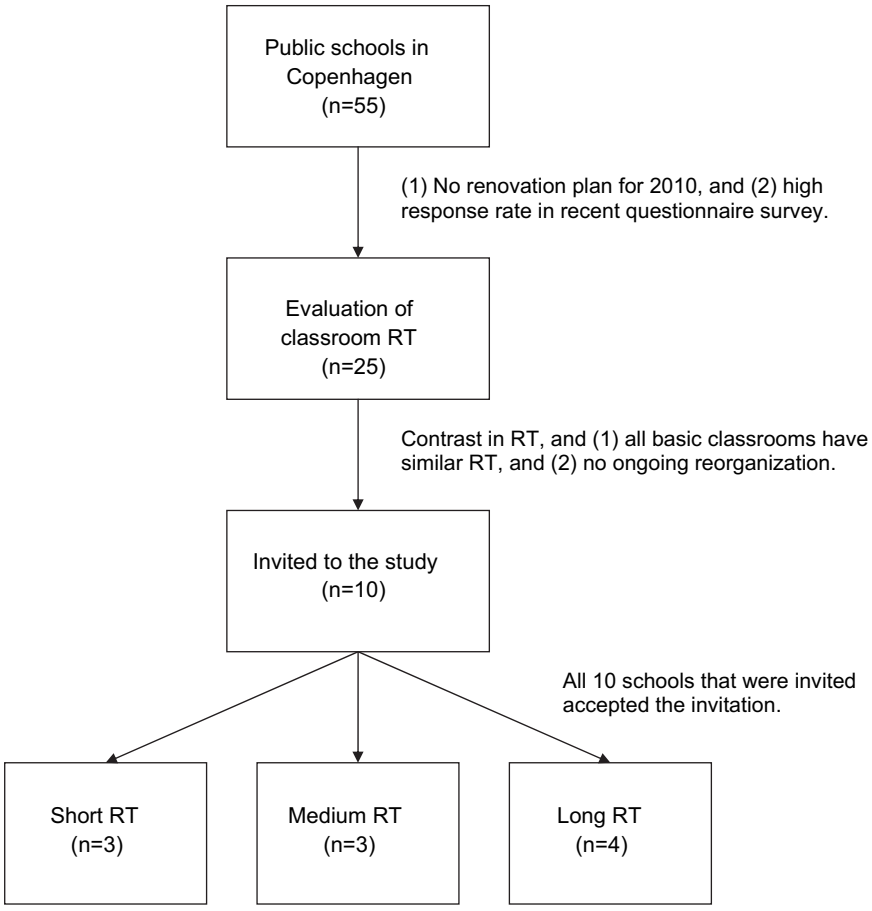

Fig. 1. Overview of the procedure for identifying and selecting 10 schools representing contrast in reverberation time of the general classrooms.

2.5. Characteristics of the work environment

Information collected using questionnaires is by definition subjective, although it may be argued that the degree of subjectivity is dependent on the phenomenon they purport to measure and the way questions are asked (Williamson, 2007). For example, Wikman (2006) has shown that the reliability of the information increases with the "hardness" of the question and response option. "Hard" questions are defined as questions that describe facts about the world and where a true value can be pointed at, while "soft" questions entail judgement and evaluation (Wikman, 2006). Likewise, quantitative specifications in the response are also associated with greater reliability than, for example, verbal scales or rating scales with boundaries indicated (Wikman, 2006). Judged by these criteria and by the content of the questions, it is clear that some questionnaire information collected from the teachers can be considered to be reliable and almost "objective" facts about the respondent's working environment. These questions entail reporting facts (numbers) and leave little room for interpretation and judgement. Examples are length of working time, the number of children in the class, the age of the children in the class, and the seniority of the teacher. Length of working time was trichotomized into $\leq$30, 30–37.5 and $>$37.5 h/week, the number of children in the class into $<$20, 20–24 and $\geq$25 children, and the age level of the class into 0–3rd, 4–6th and 7–10th grade, corresponding to ages of 6–9 years, 10–12 years, and 13–16 years. Since a teacher may have different classes during the week, the items addressing class characteristics were worded to cover only the class that the teacher faced most often, for example, "*Which class do you have most lessons with?*" to which the teacher could respond with the grade of the class (0th–10th grade). Finally, the total number of years of seniority in the teaching profession was trichotomized into $<$4 years, 4–10 years, and $>$10 years. Together with the RT classification, these variables were denoted objective work characteristics for the reasons outlined above.

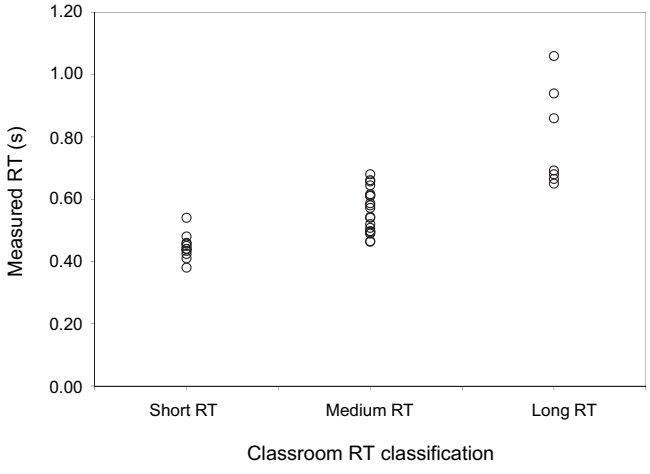

Fig. 2. Reverberation time (RT) measurements versus RT classification in 38 classrooms from 13 schools in Copenhagen.

Table 1
Characteristics of 10 schools in the study. Reverberation time (RT) was measured in representative basic classrooms in all schools except no. 17. The RT classification is based on inspection by trained experts and reverberation time measurements. ND = no data available.

Code	Postal area code	Children (n)			Teaching staff (n)	Respondents (%)	RT classification of school	RT (s)		
		Boys	Girls	Total				Mean	Range	N
14	1671 Cph. V (Copenhagen West)	67	39	106	24	88%	Short	0.41	0.38–0.43	2
18	2100 Cph. O (Copenhagen East)	226	232	458	36	89%	Short	0.45	0.44–0.46	3
20	2500 Valby	175	190	365	42	43%	Short	0.43	0.41–0.44	2
12	2700 Brønshøj	307	282	589	51	47%	Medium	0.55	0.46–0.66	4
15	2300 Cph. S (Copenhagen South)	224	230	554	60	60%	Medium	0.51	0.49–0.54	3
16	2400 Copenhagen NV (Copenhagen North-West)	313	351	664	47	70%	Medium	0.55	0.51–0.59	2
11	2450 Cph. SV (Copenhagen South-West)	227	170	397	37	59%	Long	0.65	0.61–0.68	2
13	2450 Cph. SV (Copenhagen South-West)	181	240	421	42	86%	Long	0.73	0.65–0.86	3
17	2500 Valby	198	178	379	44	80%	Long	ND	ND	ND
19	2100 Cph. O (Copenhagen East)	262	263	525	36	72%	Long	0.62	0.47–0.69	4

2.6. Workplace evaluations

Evaluation of the physical working environment was expressed as annoyance to indoor climate factors other than noise, and the influence of the psychosocial working environment was measured in terms of the working capacity relative to the mental demands. The two items used to assess these variables are shown in Table 2. With regard to annoyance to indoor factors, we constructed a combined score for indoor environment annoyance by averaging the scores for the 10 sub-items on indoor environment excluding noise. A categorical variable for indoor environment annoyance was formed based on the tertiles of the annoyance score distribution (Low, Medium, High annoyance from indoor environment conditions). With regard to the working capacity, the 5 response categories were combined to "Very good" or "Good" versus "Very bad", "Bad" or "Fair".

2.7. Confounders

Potential confounders considered were gender, age ($\leq$40; 40–54; $\geq$55 years), self-reported general health, and psychological pressure due to factors outside work. These factors may influence noise annoyance (Kjellberg et al., 1996). These factors may also theoretically influence the choice of classes (age of the children, number of children, etc.). Moreover, poor health and stress due to factors outside work may influence the perception of the workplace. Self-rated health was assessed by a single item reading "How would you rate your health overall?" For use in multivariate models, the 5 response categories were combined into 2 categories ("Good" or "Very good" versus "Very bad", "Bad" or "Fair"). The presence of psychological pressure outside work was assessed by the item "Have you within the last year felt under stress or under psychological pressure due to problems or demands outside work?" and the responses were combined to "Yes, almost all of the time or sometimes" versus "No, never, or only a few times".

2.8. Analyses

In order to qualify as a mediator, that is an intermediate variable, the candidate variable should be associated with the outcome variable and the main determinant (Baron & Kenny, 1986). Therefore, in the first part of the analyses, the basic associations between outcome variables and independent variables were investigated by bivariate partial correlation coefficients adjusted for gender. The second part of the analyses focused on assessing the quantitative relationship between determinants and outcome variables. For this purpose, multilevel, mixed-effects models with schools as a random variable were used (Albright & Marinova, 2010). The degree of clustering around schools was evaluated by calculating the intraclass correlation coefficient for the empty model (Kirkwood & Sterne, 2003). Potential determinants of noise disturbance were assessed in statistical models, with gender and health variables as a fixed categorical effect and schools as

Table 2
Items and response categories used to measure noise disturbance and determinants of disturbance.

Items	Response categories and value labels
Disturbance:	
Are you exposed to noise that disturbs you when you are teaching?	1 = Never, 2 = Rarely or very little, 3 = Approximately ¼ of the time, 4 = Approximately ½ of the time, 5 = Approximately ¾ of the time; 6 = Almost all of the time
How disturbing is noise from the following sources	
1) Noise from road, train or aeroplanes?	Discrete scale 1–7, where 1 = not disturbing and 7 = almost unbearable
2) Noise from the corridor or other classes?	Discrete scale 1–7, where 1 = not disturbing and 7 = almost unbearable
3) Noise from children in the class (for example, speech, rattling with furniture, agitation)?	Discrete scale 1–7, where 1 = not disturbing and 7 = almost unbearable
4) Noise from ventilation or machinery in the school?	Discrete scale 1–7, where 1 = not disturbing and 7 = almost unbearable
Workplace evaluations:	
How do you evaluate your current work capacity relative to the mental demands in your job?	1 = Very good, 2 = Good, 3 = Fair, 4 = Bad, 5 = Very bad
Have you within the last 3 months been annoyed by the following conditions at your work?	
1) Draught, 2) too high temperature, 3) fluctuating temperature, 4) too low temperature, 5) stuffy "bad" air, 6) unpleasant smell, 7) static electricity, 8) noise, 9) light that is too mute, 10) light reflections, 11) dust and dirt	1 = No, never, 2 = Yes, sometimes, 3 = Yes, often (every week)

a random effect. Age was included in some models (see Results, below). In the first step of the multilevel analysis, objective work characteristics entered the model (Model 1). Objective work characteristics were retained in the next step if $P < 0.20$ (Mickey & Greenland, 1989). In order to evaluate the performance of subjective workplace evaluations as intermediate variables between objective work characteristics and noise disturbance, subjective workplace evaluations were entered in the next step (Model 2). A reduction in the association between objective work characteristics and the outcome variables was considered an indication of mediation (Baron & Kenny, 1986; Kraemer, Stice, Kazdin, Offord, & Kupfer, 2001). In all analyses a two-sided $P \leq 0.05$ was considered significant. Bonferroni correction for multiple comparisons was applied where appropriate. SPSS version 18 was used in all the statistical analyses.

3. Results

3.1. Distribution of potential determinants of noise disturbance

Table 3 presents demographic characteristics, health-related variables, and selected work conditions for the total group of respondents. The majority of the respondents (83%) reported their health to be good or very good. A relative large proportion of respondents (43%) had been exposed to psychological pressure attributed to factors outside work during the last year.

In general, there were no differences between the schools defined by RT classifications, except with regard to the number of children in the class and annoyance from indoor factors other than noise (Table 3). In schools classified long RT, a markedly higher proportion of respondents (37%) scored high in annoyance from indoor factors other than noise compared to medium (18%) and short RT schools (27%).

3.2. Noise disturbance responses

The distribution of noise annoyance in terms of the proportion of teaching time that is disturbed by noise is presented in Fig. 3. Approximately 82% of the teachers reported that they are exposed to disturbing noise for at least ¼ of the workday.

Noise annoyance in terms of the disturbance rating assigned to different noise sources is shown in Fig. 4. The most significant disturbing effect is attributed to noise coming from children in the class (Fig. 4c) and noise coming from other classes or the corridor (Fig. 4b). Most of the respondents rated noise from traffic as not disturbing (60%) (Fig. 4a), and a similar pattern was observed with regard to noise attributed to ventilation or other machinery in the school, which was rated as not disturbing by 54% (Fig. 4d).

3.3. Correlations between noise variables and health and workplace characteristics

Correlation coefficients of self-reported noise exposure, rated disturbance, objective work characteristics, health variables, and subjective work evaluations are presented in Table 4. The correlation coefficients have been adjusted for gender. Noise disturbance attributed to traffic noise and ventilation and machinery in the schools was not included in this analysis because these noise sources received very low disturbance ratings from most of the respondents (Fig. 4a,d). Age was omitted from the Table because of it was highly correlated with seniority ($r = 0.853$, $P < 0.001$).

Self-reported noise exposure was significantly correlated with objective work characteristics, specifically with the number of children in the class, and negatively with the age of the children and seniority of the teacher. Disturbance attributed to noise in the class was significantly correlated with long reverberation times in the classroom and negatively correlated with seniority of the teacher. Finally, significant correlations were also observed between RT classification and annoyance to indoor factors other than noise and low ratings of work capacity, as well as between the number of children in the class and annoyance due to indoor climate factors other than noise.

3.4. Associations between objective work characteristics and noise exposure and disturbance

The correlation analysis revealed a strong co-linearity between age and seniority. We therefore conducted two parallel analyses with and without age included as confounder, respectively. Seniority was omitted from the analyses that included age.

The intraclass correlation coefficients were low at 0.022, 0.002, and 0.012 for self-reported noise exposure, disturbance attributed to noise inside the class, and disturbance attributed to noise coming from other classes, respectively. In other words, schools appear to have at most a very weak clustering effect with regard to these variables.

The main results of the multilevel modelling are presented for the models with seniority (without age) because seniority showed a stronger association with noise disturbance than age in the correlation analysis. Effect estimates, that is, the estimated difference in rating (absolute units) in the high level group relative to the reference group, are presented in Tables 5 and 6.

With regard to self-reported exposure to noise (Table 5, Model 1), significant determinants were grade of the class, number of pupils in the class and seniority of the teacher, while the RT classification was of borderline significance ($0.05 < P < 0.10$). RT classification and seniority of the teacher were significant determinants of disturbance to noise inside the class when adjusted for gender and health variables (Table 6, Model 1).

3.5. Attenuation by subjective workplace evaluations

Entering subjective workplace evaluations had a weakening effect on several of the associations found in Model 1 (Tables 5 and 6). With regard to self-reported exposure to noise, the associations with grade of the class, number of pupils, and RT classification were attenuated, but not the association with seniority (Table 5, Model 2). With regard to disturbance attributed to noise in the class, the effects of RT classification were attenuated by subjective workplace evaluations, although it remained statistically significant, while the association with seniority was once more unaffected (Table 6, Model 2). Both high annoyance due to indoor climate factors other than noise and a low-rated work capacity relative to the mental demands were significantly associated with self-reported noise exposure (both $P < 0.005$) and with disturbance attributed to noise in the class (both $P < 0.01$).

Replacing seniority with age did not overall change the outcome of the above analyses (results not shown).

3.6. Disturbance attributed to noise from other classes

Disturbance from noise attributed to children in other classes was not significantly associated with any of the objective work characteristics (not shown). Instead, self-rated health ($P < 0.05$) and annoyance to indoor factors other than noise ($P < 0.001$) were significant determinants of this outcome.

Table 3
Characteristics of the respondents and distribution between schools characterized by short reverberation time (RT), medium RT and long RT in the classrooms.

Variable	All 10 schools	3 "Short" RT schools	3 "Medium " RT schools	4 "Long" RT schools	Significance (*P*-value)[b]
Respondents (%)	283 (100%)	71 (25%)	93 (33%)	119 (42%)	
Gender					NS
Women	194 (69%)	44 (62%)	70 (75%)	80 (67%)	
Men	89 (31%)	27 (38%)	23 (25%)	39 (33%)	
Age					NS
<40 years	105 (37%)	30 (42%)	35 (38%)	40 (34%)	
40–54 years	106 (37%)	28 (39%)	28 (30%)	50 (42%)	
55 + years	72 (25%)	13 (18%)	30 (32%)	29 (24%)	
Marital status					NS
Married or living with partner	192 (68%)	45 (64%)	66 (72%)	81 (68%)	
Single	89 (32%)	25 (36%)	26 (28%)	38 (32%)	
Children living at home					NS
None (0)	128 (45%)	34 (48%)	38 (41%)	56 (47%)	
1 child	62 (22%)	17 (24%)	24 (26%)	21 (18%)	
2 children	77 (27%)	19 (27%)	24 (26%)	34 (29%)	
3 or more children	16 (6%)	1 (1%)	7 (8%)	8 (7%)	
Smoking					NS
Current smoker	74 (26%)	23 (32%)	20 (22%)	31 (26%)	
Former smoker	99 (35%)	26 (37%)	32 (34%)	41 (34%)	
Have never smoked	110 (39%)	22 (31%)	41 (44%)	47 (39%)	
Health					
Self-rated health					NS
Good-very good	235 (83%)	59 (83%)	77 (83%)	99 (83%)	
Fair-less good	48 (17%)	12 (17%)	16 (17%)	20 (17%)	
Psychological pressure outside work					NS
Yes	122 (43%)	35 (49%)	35 (38%)	52 (44%)	
No	160 (57%)	36 (51%)	57 (62%)	67 (56%)	
Subjective work evaluation					
Annoyance to indoor factors other than noise					$P < 0.001$
Low	93 (33%)	17 (24%)	48 (52%)	28 (24%)	
Medium	110 (39%)	35 (49%)	28 (30%)	47 (39%)	
High	80 (28%)	19 (27%)	17 (18%)	44 (37%)	
Work capacity relative to mental demands					$P = 0.084$
Good	211(74%)	60 (84%)	66 (71%)	85 (71%)	
Fair-not god	72 (26%)	11 (16%)	27 (29%)	72 (29%)	
Objective work characteristics					
Work hours/week					NS
≤30	55 (19%)	8 (11%)	21 (23%)	26 (22%)	
30–37	144 (51%)	38 (54%)	43 (46%)	63 (53%)	
>37	84 (30%)	25 (35%)	29 (31%)	30 (25%)	
Seniority in years[a]					NS
≤4	49 (17%)	12 (17%)	15 (16%)	22 (18%)	
4–10	83 (29%)	21 (30%)	28 (30%)	34 (29%)	
>10	150 (53%)	38 (54%)	49 (53%)	63 (53%)	
Grade (where most of the lesson are placed)					NS
0–3rd grade	108 (38%)	26 (37%)	36 (39%)	46 (38%)	
4th–6th grade	87 (31%)	21 (30%)	28 (30%)	38 (32%)	
7th–10th grade	88 (31%)	24 (34%)	29 (31%)	35 (29%)	
Number of children in the class (most of the lessons with this class)					$P = 0.02$
<20	124 (44%)	30 (42%)	31 (33%)	63 (53%)	
20–24	102 (36%)	31 (44%)	39 (42%)	32 (27%)	
≥25	57 (20%)	10 (14%)	23 (25%)	24 (20%)	
Primary subject (most of the lessons in this subject)					NS
Danish	132 (47%)	39 (55%)	40 (43%)	53 (45%)	
Math	67 (24%)	15 (21%)	25 (27%)	27 (23%)	
English	14 (4.9%)	3 (4.2%)	4 (4.3%)	7 (5.9%)	
Needlecraft, woodwork or home economics	12 (4.2%)	2 (2.8%)	6 (6.5%)	4 (3.4%)	
Other subjects	58 (20%)	12 (17%)	18 (19%)	28 (24%)	

[a] 282 valid responses.
[b] Significant difference between distributions by RT classification, *Chi*-square test, NS = not significant.

4. Discussion

A high proportion of 82% of the teachers studied were disturbed by noise for at least ¼ of the working time. In addition, the children were the most disturbing sound source. These findings are in line with results of other studies showing that noise annoyance in teachers is associated with chatter and sounds from the corridor, while traffic, ventilation, machinery etc. accounts for much less of the disturbance (Enmarker & Boman, 2004; Tesarz & Kjellberg, 1998).

With regard to the determinants of self-reported noise exposure, our results showed that the age of the children, the number of children in the class, and the seniority of the teacher were significant determinants. Disturbance attributed to noise inside the class was associated with long RT classification of the school and with low seniority of the teacher. Corroborating these findings, other

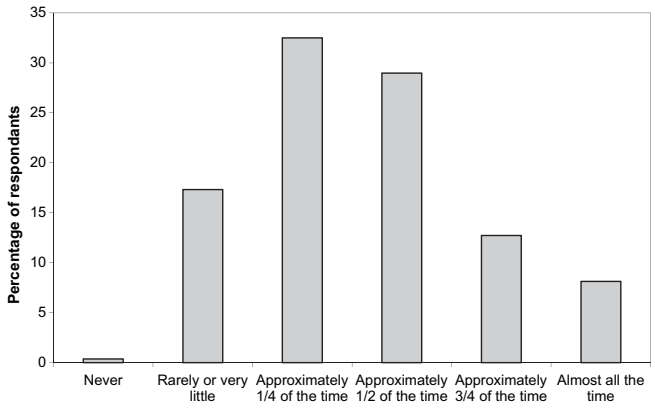

Fig. 3. Distribution (percentage) of 283 responses to the item "Are you exposed to noise that disturbs you when you are teaching?".

studies have shown that measured classroom sound levels decrease with increasing age of the children (Picard & Bradley, 2001), although the association is not always strong (for example, Shield and Dockrell (2004)).

That seniority of the teacher was a relatively strong predictor of noise disturbance is a new finding, and it raises the question of how to interpret this association. It could be, as hypothesized in the introduction, that high seniority is an expression of experience and pedagogical competences which are used to maintain good order, leading to lower sound levels in the class. Experienced teachers may also feel more confident even in "noisy" circumstances, and this may lead to a lower perceived noise exposure, although the lessons would not necessarily be associated with low actual sound levels. A "healthy worker effect" can also not be ruled out if teachers that perceive noise as a substantial problem quit their job or find jobs at other schools.

The number of children in the class was significantly associated with self-reported noise exposure, however, not in a strict dose-dependent way (Table 5). The deviation from a dose–response trend might be due to the relatively low number of responses related to large classes (54 responses) compared to small and medium sized classes (124 and 102 responses, respectively). It is also conceivable that awareness of noise problems is higher in large classes, which paradoxically might reduce the problem. That the size of the class could be an important determinant of noise problems is supported by the observation of significant correlation between measured classroom sound levels and the number of children in London schools (Shield & Dockrell, 2004).

The RT classification played a significant role for the disturbance attributed to noise from children in the class, and there was also a tendency that long RT classification was associated with higher self-reported noise exposure. To our knowledge, this is first time an association between classroom reverberation time (RT) and noise annoyance in teachers has been demonstrated. Clear association between classroom RT and sound levels during teaching have been found in an earlier study (Oberdörster & Tiesler, 2006). The higher sound levels may be mediated by an effect by which the speech levels of children increase due to reflected sounds (Nijs et al., 2008; Schick, Klatte, & Meis, 2000). Interestingly, negative effects of long classroom RT on the wellbeing of the children and on their perceived relation to the teacher have been found in a recent study (Klatte, Hellbrück, Seidel, & Leistner, 2010). Specifically, children in classrooms with long RT perceived the teacher to be more unfriendly, more impatient, and to have less time to help, compared to children in classrooms with short RT. According to Klatte et al. the explanation might be that teachers in classrooms with poor acoustics have to raise their voice level more than other teachers,

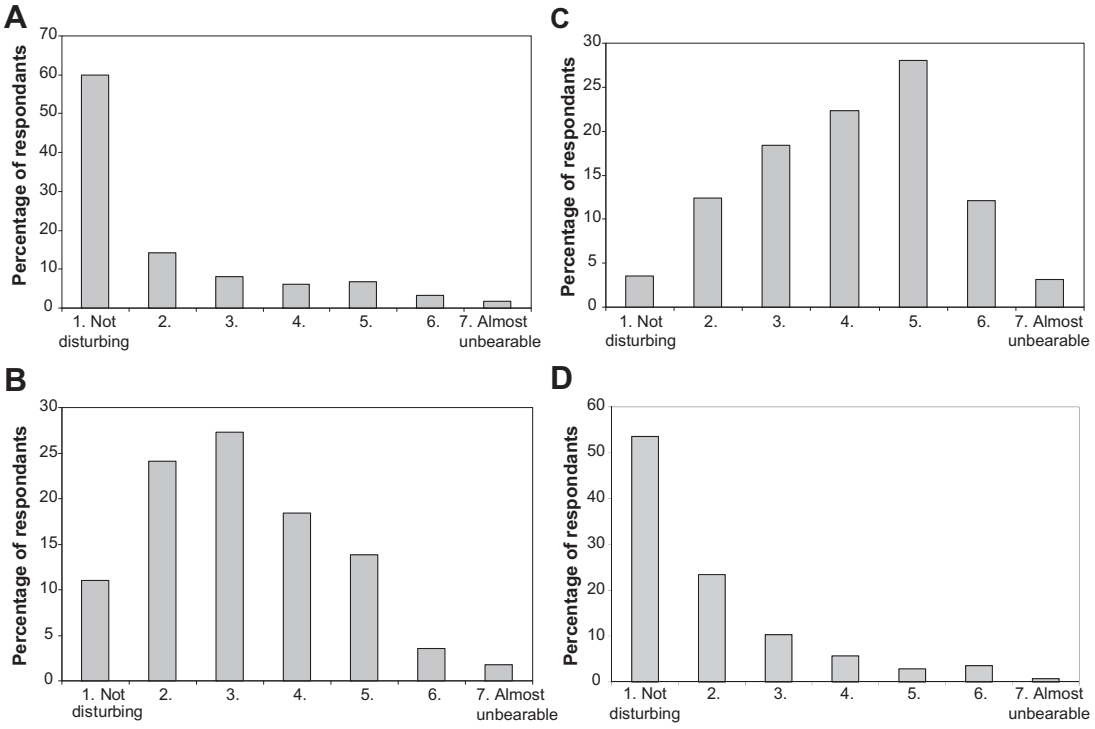

Fig. 4. Distribution (percentage) of 282 responses to the item "How disturbing is noise from the following sources" with the subcategories (A) "Noise from road, train or aircrafts?"; (B) "Noise from the corridor or other classes?"; (C) "Noise from children in the class (for example, speech, rattling with furniture, agitation etc.)?"; (D) "Noise from ventilation or machinery in the school.

Table 4
Bivariate partial correlation coefficients of noise disturbance, health variables, objective and subjective work characteristics. Adjusted for gender. Correlation coefficient r significantly different from zero, $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$. Two-sided significance test ($n = 283$).

		Noise variables		Health		Objective work characteristics					Workplace evaluations	
		2	3	4	5	6	7	8	9	10	11	12
1	Exposure to disturbing noise during teaching	0.570***	0.199***	0.058	0.147*	0.107	−0.175**	0.220***	−0.018	−0.241***	0.238***	0.259***
2	Degree of disturbance from noise attributed to children in the class	1.000	0.221***	0.105	0.218***	0.130*	−0.109	0.069	0.006	−0.290***	0.231***	0.259***
3	Degree of disturbance from noise attributed to children in other classes		1.000	0.136*	0.116	0.024	0.012	0.085	0.037	−0.092	0.414***	0.142*
4	Self-rated health (low rating = good health)			1.000	0.245***	−0.039	−0.079	0.021	−0.005	0.077	0.040	0.302***
5	Psychological pressure outside work				1.000	−0.001	−0.060	0.088	0.005	−0.095	0.196***	0.243***
6	RT classification					1.000	−0.019	−0.057	−0.125*	−0.007	0.137*	0.160**
7	Age of the children						1.000	−0.098	0.048	0.098	−0.062	−0.022
8	Number of children in the class							1.000	0.103	−0.111	0.180**	0.103
9	Length of working time								1.000	−0.015	0.001	0.012
10	Seniority									1.000	−0.007	−0.092
11	Annoyance to indoor factors other than noise										1.000	0.171**
12	Work capacity relative to mental demands (high rating = low capacity)											1.000

which is strenuous, they have to repeat the messages more often, which interrupts the flow of instruction, and they have to tell the children to be quiet more frequently. Thus, the study by Klatte et al. clearly corroborates our findings, although it should be noted that the range of classroom RT was greater in the study by Klatte et al (from 0.5 to 1.1 s) than in the present study. Noteworthy is also the study by Blomkvist et al. These authors found an improvement in the perceived psychosocial working environment among the staff working in a hospital critical care unit after reducing the RT and improving speech clarity at the workplace (Blomkvist, Eriksen, Theorell, Ulrich, & Rasmanis, 2005). These studies support the view that acoustic conditions are important determinants for the perceived sound environment. Optimal RT in classrooms has for long time been recognized as an important parameter for vocal effort among teachers (Pekkarinen & Viljanen, 1991; Yang & Bradley, 2009). Moreover, the RT in classrooms is also important in order to hear what is being said. Young children, who have not yet acquired the ability to guess incorrectly heard speech sounds, and children with hearing problems are particular vulnerable to noise and poor acoustics (Bradley & Sato, 2008; Elliott, 1979; Elliott et al., 1979; Flexer, 2004). Importantly, even when spoken messages are correctly heard, poor acoustics in the form of long RT may interfere with memory consolidation and learning (Ljung & Kjellberg, 2009; Ljung et al., 2009). Danish building regulations recommend that RT in classrooms be below 0.6 s in new schools (Erhvervs- og Byggestyrelsen, 2008). Obviously, the 4 schools classified as "long RT" schools in this study did not fulfil this recommendation.

Interestingly, the association between noise outcomes, RT classification and the number of pupils in the class was markedly reduced by introducing subjective workplace evaluations in the statistical models. The most important factor in attenuating the associations with noise exposure and disturbance was work capacity, which the teacher was asked to rate relative to the mental demands. This adds further evidence to the above suggestion, that the impact of poor classroom acoustics may not be limited to negative evaluations of the sound environment, but may have a broader impact on the evaluation of the working environment.

Length of working time has been observed to be associated with noise annoyance in, for example, office workers (Banbury & Berry, 2005; Kjellberg et al., 1996), but we did not see an effect in school teachers. The differences in length of working time length may have been too limited in the group in this study.

In principle, it is not possible in a cross-sectional design to establish causal relationships. Although reverse causality therefore cannot be excluded, it seems more likely that the work characteristics investigated here (specifically, long RT, class grade 0–3rd, and seniority < 4 years of the teacher) are causes for noise annoyance than the other way round. Some other points should be addressed when evaluating the implications of the results. First, we did not

Table 5
Effect estimates (difference between the high level and the reference level), 95% confidence intervals and significance levels of objective and subjective working environment characteristics in multivariate mixed model regression of self-reported exposure to noise that disturbs the teaching. Model 1: Objective work characteristics. Model 2: Subjective workplace evaluations added to Model 1. All models were adjusted for gender and health variables. New determinants were retained in higher models if $P \leq 0.20$. A dash ("-") indicates that the variable was not included in the model.

Determinant (reference level)	High level	Model 1			Model 2		
		Estm.	95% CI	*P*	Estm.	95% CI	*P*
Acoustic classification	Medium RT	0.17	(−0.23–0.57)	>0.20	0.23	(−0.33–0.79)	>0.20
(Short RT)	Long RT	0.36	(−0.02–0.74)	0.064	0.25	(−0.27–0.78)	>0.20
Grade of the class	4th–6th	0.32	(−0.06–0.70)	0.120	0.20	(−0.17–0.57)	>0.20
(7th-10th grade)	0–3rd	0.49	(0.13–0.85)	0.005	0.44	(0.09–0.79)	0.010
Length of working time	31–37 h/week	0.17	(−0.23–0.57)	>0.20	–	–	–
(<31 h/week)	>37 h/week	0.16	(-0.28–0.60)	>0.20	–	–	–
Number of pupils in the class	20–24	0.41	(0.07–0.76)	0.015	0.27	(−0.07–0.61)	0.148
(<20)	>24	0.31	(−0.10–0.73)	0.183	0.14	(−0.29–0.57)	>0.20
Seniority	4–10 years	0.32	(−0.02–0.67)	0.067	0.36	(0.03–0.69)	0.029
(>10 years)	<4 years	0.77	(0.36–1.18)	<0.001	0.78	(0.38–1.17)	<0.001

Table 6
Effect estimates (difference between the high level and the reference level), 95% confidence intervals and significance levels of objective work characteristics and subjective workplace evaluations in multivariate mixed model regression of disturbance by noise coming from the class. Model 1: Objective work characteristics. Model 2: Subjective workplace evaluations added to Model 1. All models were adjusted for gender and health variables. See Table 5 for further details.

Determinant (reference level)	High level	Model 1			Model 2		
		Estm.	95% CI	*P*	Estm.	95% CI	*P*
Acoustic classification	Medium RT	0.35	(−0.14–0.85)	>0.20	0.45	(−0.04–0.94)	0.081
(Short RT)	Long RT	0.56	(0.10–1.03)	0.014	0.46	(0.01–0.91)	0.046
Grade of the class	4th–6th	0.44	(−0.03–0.91)	0.075	0.29	(−0.17–0.75)	>0.20
(7th-10th grade)	0–3rd	0.38	(−0.08–0.83)	0.123	0.31	(−0.13–0.74)	>0.20
Length of working time	31–37 h/week	0.15	(−0.34–0.65)	>0.20	–	–	–
(<31 h/week)	>37 h/week	0.18	(−0.37–0.72)	>0.20	–	–	–
Number of pupils in the class	20–24	0.38	(−0.04–0.81)	0.085	0.21	(−0.21–0.63)	>0.20
(<20)	>24	−0.10	(−0.62–0.42)	>0.20	−0.28	(−0.77–0.22)	>0.20
Seniority	4–10 years	0.38	(−0.05–0.80)	0.091	0.41	(0.00–0.82)	0.049
(>10 years)	<4 years	0.98	(0.46–1.48)	<0.001	0.98	(0.49–1.47)	<0.001

adjust for noise sensitivity, which is a well-known strong determinant of noise annoyance (Guski, 1999). However, the methodological issues in measuring noise annoyance reactions and noise sensitivity in the same questionnaire are widely acknowledged. Moreover, the results can hardly be explained by confounding by noise sensitivity, as this would mean that, for example, noise-sensitive teachers should prefer to work in poor acoustic conditions and with young classes (where sound levels are highest), which is difficult to imagine. Second, we did not include a variable for the socio-economic status of the pupils, because the mechanism by which socio-economic status may influence the objective work characteristics and noise disturbance is unclear. If, for example, the children's socio-economic status has an effect on the quality of the classroom, and thus, the acoustics of the room, then adjustment for socio-economic status would be tantamount to overcorrection. Third, some of the objective work characteristics have been measured imprecisely, in particular the grade of the class and the age of the children. This will most likely have weakened the associations rather than creating biased findings. Fourth, the contrast with respect to actual RT between schools classified as "short RT" and "long RT" were small, for example, compared to the classroom RT measured in the study by Klatte et al. (2010). The reason is that it was required that participating schools have classrooms with similar RT. This excluded some schools with one or a few classrooms with more extreme RT. Nevertheless, our data indicate a clear gradient in RT. Also, we find significant effects associated with the RT classification, which mitigate the argument that the contrast between schools is too small. Furthermore, it could be argued that increased background sound levels due to long RT in the classroom, and not the RT in itself, are the true cause of perceived noise exposure and disturbance. This may indeed be true, but that does not make RT unimportant or a confounder. Rather, sound levels act as an intermediate variable between RT and disturbance. Furthermore, with regard to the statistical analysis, it may be argued that the number of schools is too low to provide a reliable estimate of the variance components associated with the schools. However, the intraclass correlation coefficients show that the clustering effect is very small. Accordingly, this limitation has no, or only a very minor, practical and statistical importance. Finally, it should be emphasized that the participating schools were not recruited as representative for all Danish schools. This means that neither the measured RT nor the proportion of teachers experiencing noise annoyance is representative for Danish classrooms or teachers, respectively.

In conclusion, the results of this study indicate that the physical working environment may influence perceived noise exposure and disturbance attributed to noise coming from the class, but not with regard to disturbance attributed to noise coming from other classes and the corridors. The perceived working capacity mediated some of these relationships, suggesting the possibility that the determinants of noise disturbance have a widespread negative effect on how people evaluate the working environment.

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