CLASSROOM NOISE

-Exposure and subjective response among pupils-

Pär Lundquist
In Sweden, all children must have access to education of equal value and the curriculum points out the importance of a good environment for development and learning. Modern working methods differ a lot from the traditional. Teaching nowadays is focused on problem-solving. Students are more interactive, working in groups and projects. The teacher has become a supervisor, guiding not lecturing.

Hearing loss, vegetative responses, biochemical effects, speech interference, behavioural effects and subjective reactions are all part of the problem of noise exposure. There is no unequivocal method of assessing noise and its effects. The most common method of noise assessment and appraisal of negative noise reactions is based on measurement of acoustic characteristics. Recommendations made and targets set by authorities are often stated in terms of equivalent A-weighted sound level L (A) eq.

The purposes of this thesis have been to increase knowledge of noise exposure in classrooms and the subjective response among pupils and also to identify factors of special importance when assessing negative noise effects in the classroom. The work consists of five separate articles considering different aspects of sound exposure and its adverse effects on pupils in school: three field studies, one article on development of a mood-rating instrument and one laboratory study. Analyses of exposure were based on equivalent sound levels and subjective responses were evaluated using ratings on a visual analogue scale and forced choice questions.

The results point to speech and structure-borne sounds as the most annoying sound sources to the pupils. Annoyance will increase with variability of the exposure. This is typical of the character of structure-borne sounds such as footsteps, scraping of chairs and tables and slamming of doors, as well as of speech.

The background sound level exposure levels in the classrooms ranged between 33 and 42 dB(A) eq. The background sound in about 2/3 of the classrooms investigated was considered to be LFN. Pupils exposed to high LFN levels were not more annoyed than pupils exposed to low LFN levels.

The activity sound level ranged between 47 and 69 dB(A) eq. These are levels that must be considered high for a work environment such as the school, which has at all times to be conducive to steady concentration, communication and learning. The risk of hearing damage during this exposure must be considered as low.

The thesis also describes the development of a mood-rating instrument to identify effects of noise and other aspects of the classroom environment. The questionnaire is easy to administer, takes little time to complete and is therefore well suited to studies in field settings.

The ratings of annoyance in the classroom correspond to the verbal definition "Somewhat annoying - Rather annoying". Data from the field studies does not support the idea that the negative response will increase with higher sound levels. In the laboratory setting, a relationship between increasing sound level and increase in rated annoyance was displayed.

Keywords: school, teaching, students, annoyance, children, sound, mood
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AKADEMISK AVHANDLING

som med vederbörligt tillstånd av Rektorsämbetet vid Umeå Universitet
för avläggande av medicine doktorsexamen,
kommer att offentligen försvaras i

Stora föreläsningssalen, ALI Norr,
torsdagen den 5 juni 2003, klockan 13.00

av

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Fakultetsopponent: Docent Rauno Pääkkönen, Tampere Regional Institute of Occupational Health, Tampere, Finland
CLASSROOM NOISE

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Umeå 2003
"Till örat genom luftens vågor fortplantar sig livets stora frågor. 
Men livets stora svar, jag undrar vilken väg dom tar."

Tage Danielsson
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In Sweden, all children must have access to education of equal value and the curriculum points out the importance of a good environment for development and learning. In the classroom, as many as 30 pupils and a teacher are working together. Modern working methods differ a lot from the traditional. Teaching nowadays is focused on problem-solving. Students are more interactive, working in groups and projects. The teacher has become a supervisor, guiding not lecturing.

Hearing loss, vegetative responses, biochemical effects, speech interference, behavioural effects and subjective reactions are all part of the problem of noise exposure. There is no unequivocal method of assessing noise and its effects. The most common method of noise assessment and appraisal of negative noise reactions is based on measurement of acoustic characteristics. Recommendations made and targets set by authorities are often stated in terms of equivalent A-weighted sound level $L(A)_{eq}$.

The purposes of this thesis have been to increase knowledge of noise exposure in classrooms and the subjective response among pupils and also to identify factors of special importance when assessing negative noise effects in the classroom. The work consists of five separate articles considering different aspects of sound exposure and its adverse effects on pupils in school: three field studies, one article on development of a mood-rating instrument and one laboratory study. Analyses of exposure were based on equivalent sound levels and subjective responses were evaluated using ratings on a visual analogue scale and forced choice questions.

The results point to speech and structure-borne sounds as the most annoying sound sources to the pupils. In the literature, speech appears to be more disturbing than other sources, and annoyance as well as negative effects on performance will increase with variability of the exposure. This is typical of the character of structure-borne sounds such as footsteps, scraping of chairs and tables and slamming of doors, as well as of speech.

The sound levels in empty classrooms were mainly due to ambient noise from ventilation, other classrooms and corridors. The background sound level exposure levels in the classrooms were distributed within the interval of 33 - 42 dB(A)_{eq}. The background sound in about 2/3 of the classrooms investigated was considered to be LFN. Pupils exposed to high LFN levels were not more annoyed than pupils exposed to low LFN levels when the $L_{eq} - L_{Aeq}$ difference was used to identify LFN.

The activity sound level ranged between 47 and 69 dB(A)_{eq}. These are levels that must be considered high for a work environment such as the school, which has at all times to be conducive to steady concentration, communication and learning. The risk of hearing damage during class - music, woodwork and gymnastics excluded - is low.

The thesis also describes the development of a mood-rating instrument to identify the effects of noise and other aspects of the classroom environment of importance to the children’s scholastic performance. The questionnaire that is involved is quite easy to
administer, takes little time to complete and is therefore well suited to studies in field settings.
The ratings of annoyance in the classroom correspond to the verbal definition "Somewhat annoying - Rather annoying". Data from the field studies does not support the idea that higher sound levels increase annoyance and inattentiveness, or impair task orientation. In the laboratory setting, a relationship between increasing sound level and increase in rated annoyance was displayed.
This thesis is based on the following papers referred to by their Roman numerals:


This Thesis was financed by grant from Swedish Council for Work Life Research.
INTRODUCTION

The most obvious role of the school is to educate, to foster cognitive development, to transmit information about the subjects of the curriculum, and to communicate joy and excitement about education (Rivlin and Weinstein 1984). To transmit the ideas and values of society, prepare children for their adult roles and responsibility and support each individual's psychological development is central.

All children - irrespective of gender, geographical place of residence and social and economic conditions - must have access to education of equal value (Ministry of Education and Science 1997) and the curriculum points out the importance of a good environment for development and learning (Ministry of Education and Science and National Agency for Education 2001).

A recent study by the Swedish National Board of Occupational Safety and Health (2003) points out that "noise and acoustic problems" are among the most common environmental problems in schools in Sweden. Pupils spend about 45% of the school day engaged in listening activities (Berg 1987) and the daily activities in the classroom are based on communication and concentration.

In Sweden, school is the largest place of work, with approximately 1.5 million people active there (Statistics Sweden 2003), and since 1990 the Swedish Occupational Safety and Health Act has covered all pupils at school from the first grade. The purpose of the Act is to prevent ill-health and accidents at work and generally to ensure a good working environment. The foundation of the Act is that the working environment should be satisfactory with regard to the nature of the work and to the social evolution and technological development of society. Working conditions should be adapted to people's differing physical and mental aptitudes. Work should be planned and arranged in such a way that it can be carried out in healthy and safe surroundings, equipped to provide a suitable
working environment in which atmospheric, acoustic and lighting conditions are satisfactory.

The Swedish National Board of Occupational Safety and Health has also issued special regulations on noise (Swedish National Board of Occupational Safety and Health 1992). The statute book points out that it is impossible to indicate a general connection between exposure and subjective annoyance. However, for teaching and other activities demanding steady concentration and/or undisturbed communication a maximum equivalent sound level exposure during normal working day of 40 dB(A) is recommended to avoid annoyance. Sound contributed by the individual's own activity is not to be included. Further, the statute book emphasizes that conditions often require a careful review of the working premises and sources of the noise problem and that it may be appropriate to try to rank the sources in terms of disturbance, number of people affected, type of action which can be taken, and the cost and benefits of measures against the noise problem (Swedish National Board of Occupational Safety and Health 1992).

The National Board of Health and Welfare in Sweden points out that school is a critical environment since noise affects speech communication and concentration and that classrooms may require background sound levels as low as 25 dB in order to reach an acceptable speech intelligibility for certain sensitive groups (National Board of Health and Welfare 1996).

The following chapters present a brief overview of noise, noise exposure and its effects as a basis for the presentation and discussion of objectives and results from five studies on noise exposure and subjective responses among pupils in classroom environments.
BACKGROUND

Noise

Depending on the context there are many ways to describe a sound. In a physical sense sound is mechanical oscillations propagated as a wave motion in an elastic medium. The concept of sound may also be defined psycho-physically, as an auditory perception.

Noise is generally defined as unwanted sound (World Health Organisation 1980). Unwanted because it can be perceived as unpleasant or bothersome, it interferes with activities or it is believed to be physiologically harmful in some way (Kryter 1970). It is therefore impossible to define noise exclusively on the basis of physical parameters (Berglund and Lindvall 1995).

Appraisal of noise

Despite the extensive concern over too much noise, there is no unequivocal method of assessing noise and its effects. The most common method of noise assessment and appraisal of negative noise reactions is based on measurements of the acoustical characteristics.

The equivalent A-weighted sound pressure level, $L_{A(eq)}$, is commonly used to quantify noise exposure (Sailer and Hassenzahl 2000). Recommendations and objectives from authorities are often stated in terms of equivalent A-weighted sound level (e.g. Swedish National Board of Occupational Safety and Health 1992). The A-weighting of a sound is intended to indicate a level with a closer relation to loudness (the perceived sound level) than the unweighted sound pressure level, adapted for risk assessment of hearing damage as well as annoyance. A young person, with no hearing impairment, perceives sounds within the frequencies 20 - 20 000 Hz. The same sound level at different frequencies is not perceived in the same way. Extensive research, initiated by
Background

Fletcher and Munson (1933), has led to the ISO standardised equal loudness curves (International Standardization Organization, 1985).

The A-weighting resembles the inverted equal loudness curve for 40 phone. Phone is the unit for loudness level.

Equivalent A-weighted sound pressure level is the mean root mean square-value of a sound pressure variation over a specific time period. It is the level of a steady sound that, over a stated time period and at a stated location, has the same A-weighted sound energy as the time varying sound (Harris 1979).

One question that has been raised is whether frequency weighting with an A-filter gives a correct result when assessing annoyance and other subjective responses to noise, especially noise containing strong low-frequency noise (LFN) components (Persson Waye 1995; Holmberg 1997). The interval between the hearing threshold and an unacceptable level is much smaller for LFN than for noise at higher frequencies (International Standardization Organization 1985). At LFN exposure, annoyance thus may appear close to the hearing threshold level. Persson Waye (1995) presents results indicating that annoyance experienced from LFN is greater than annoyance from noise without dominant LFN components at the same A-weighted sound pressure level.

The definition of LFN varies and there is no internationally agreed definition. Berglund et al. (1996) suggest that frequencies up to 250 Hz should be regarded as LFN. Dealing with annoyance, an appropriate definition of LFN could be noise with a dominant frequency content of 20 to 200 Hz (Persson Waye 1995). One method that has been used in some Swedish recommendations on identification of LFN is the dB(C) - dB(A) difference (Swedish National Board of Health and Welfare 1996). This will constitute an estimate of how much energy is to be found in the low frequency part. A limit of 15-20 dB is also given, above which the noise is to be considered to be LFN (Swedish National Board of Health and Welfare 1996). Persson Waye (1999) suggests that this method should only be used when the level is above 30 dB(A).
Background

**Noise exposure in classrooms**

In the classroom, as many as 30 pupils and a teacher are working together. The working methods differ a lot from the traditional lecturing methods. Teaching nowadays is focused on problem-solving. Students are more interactive, working in groups and projects. The teacher has become a supervisor, guiding not lecturing. Due to these changes most of the noise is likely to originate from human activities. A Danish survey (Bredo 2000) identifies chatter and laughter, noise from chairs and tables, and noise from other classrooms as the forms of noise most annoying to the pupils.

Schools, business premises, service institutions and offices are examples of environments where speech is often regarded as a serious problem (Kjellberg and Landström 1994; Landström et al. 2002). A study by Kjellberg and Sköldström (1991) indicates speech to be more disturbing than meaningless random noise and in a recent study speech was found to be more disturbing than meaningless noise when difficult verbal tasks were being performed (Landström et al. 2002). Annoyance and effort ratings were higher and performance ratings lower in speech than in broadband noise conditions. The effects were more pronounced during verbal tasks than during work without verbal information. Irrelevant speech may also cause annoyance and interfere with the performance of several tasks requiring retention of verbal material (Jones and Morris 1992, Tremblay et al. 2000).

A specific type of noise exposure in the classroom is that caused by footsteps, chairs, tables and doors. The hazard of this type of activity is complicated by the prominent risk of transmission through the building structure, i.e. the propagation of structure-borne noise. Due to its temporal character, sounds from footsteps, doors, etc may be a critical part of the sound climate in the classroom.

Generally noise emitted from individual equipment, computers, projectors, etc is restricted in time and probably responsible for only a minor part of the noise in classrooms.

Practically all types of indoor environments are equipped with a ventilation system. A large number of people are affected and complaints about ventilation noise have increased in recent years. Ventilation noise has attracted particular attention in environments such as offices, schools, and public areas (Landström 2001). Ventilation noise originates primarily from fans and the air turbulence.
generated inside ducts and around air supply and exhaust. Studies on effects of ventilation noise point out increased negative effects such as disturbance with increasing level, at higher frequencies, increased exposure time and when the ventilation noise is intermittent (Landström et al. 1991; 1994; 1996; Holmberg et al. 1993).

Noise from outdoor sources are another part of the noise exposure in classroom environments. In school environments road traffic as well as air traffic, railways and construction work may also contribute to annoyance and effects on performance (Hygge et al. 2003).

**Sound levels in classrooms**

According to Berg et al. (1996) the typical sound level in an occupied classroom is 60 dB(A), but noise levels as high as 75 - 85 dB(A) have been recorded in some classrooms (Ross 1982; Finitzo 1988).

Reported measurements of classroom ventilation noise levels range from 23 - 55 dB (A) (Bess et al. 1984; Markides 1986; Pekkarinen and Viljanen 1991; Crandell and Smaldino 1994) and for pupil activities the literature reports sound levels in the range 40 -70 dB(A) (Markides 1986; Pekkarinen and Viljanen 1991).

Airey et al. (1998) measured noise in approximately 60 classrooms in the United Kingdom in two different conditions: pupils silent and pupils working and talking under normal conditions. The classrooms were divided into three categories according to their design: open-plan schools, cellular classrooms and classrooms with specific acoustic treatment.

The results show that the open-plan schools had a somewhat higher background sound level when the pupils were silent (49 - 70 dB(A)) than cellular classrooms (31 - 68 dB(A)) and acoustically treated classrooms (34 - 55 dB(A)). However, open-plan schools were quieter during active lessons (60 - 84 dB(A)) than cellular classrooms (52 - 101 dB(A)), but somewhat higher than in the acoustically treated classrooms (59 - 79 dB(A)). This was explained by higher reverberation times in cellular classrooms. Teachers in the open-plan classrooms also tended to adapt their lessons to avoid disturbing other classes. The lower noise levels in the acoustically treated classrooms are to some extent a reflection of the spirit of these classrooms (Airey et al. 1998).

Despite the change in teaching methodology, Crandell and Smaldino (1994) pointed out that noise levels have shown little change over recent decades.
Background

Effects of noise

Until the mid-seventies, knowledge of and conclusions about effects of noise exposure on children were for the most part based on extrapolations from studies on adults. Such extrapolations are questionable. Airey et al. (1998), for example, claim that children’s listening skills are not yet fully developed and that they are more easily distracted by background noise than adults. Today interest in studying environmental noise effects on children is growing, although most research on the effects of noise on pupils has dealt with air, rail, and road traffic noise (Bronzaft and McCarthy 1975; Hygge et al. 1993; Evans and Lepore 1996; Haines et al. 2000).

Hearing loss

Very high sound pressure levels may burst the eardrum, cause immediate damage to the middle ear structure and instantly and permanently damage hair cells in the inner ear. Long-term exposure to high sound levels may destroy the hair cells of the inner ear resulting in a cochlear hearing loss (Johansson 2003).

In studies where the sound exposure level was known, a clear relationship was seen between increasing incidence of hearing loss and increasing sound level (Berglund and Lindvall 1995). Hearing loss among workers in noisy industries has been known for a long time. A common estimation is that 15 – 20% of the working population are affected by sound pressure levels of 75 - 85 dB(A) in industrialized countries (Berglund and Lindvall 1995).

ISO 1999 presents standardised risk criteria based on sound levels to represent the risk of damage to the inner ear (International Standardization Organization 1990). The risk of noise-induced hearing loss depends on the duration of the exposure. The critical level, based on a dose-effect assumption, is set at 85 dB(A) for 8 hours per day. According to the equal-energy principle an increase by 3 dB would halve the duration. This implies a maximum of 28 seconds of noise exposure at 115 dB(A). For impulse sounds of short duration the peak level may cause a permanent threshold shift regardless of the total energy.

The Swedish legislation for occupational environments (Swedish National Board of Occupational Safety and Health 1992) specifies the exposure values for noise with reference to the risk of hearing impairment. The limit for exposure to equivalent sound pressure level during 8 hours, five days a week, is set at 85 dB(A), for exposure to maximum sound pressure level at 115 dB(A) and for exposure to maximum peak level of impulse sound at 140 dB(C).
On the basis of the sound level/effect relationship for hearing loss and the known exposure levels in classrooms it would seem that the risk of hearing damage is likely to be low. Critical noise levels may be attained during music lessons, gymnastics and woodwork instruction.

Tinnitus, the perception of a sound without cause in an acoustical signal, is often associated with hearing loss, although it is considered that factors other than sound exposure may be the cause (Johansson 2003).

**Vegetative responses and biochemical effects of noise**

Rehm (1983) has summarized results from studies that have been focused on physiological effects of noise. Sudden changes in acoustic surroundings may activate several physiological systems leading to such changes as increase in blood pressure (Andrén et al. 1978) and circulatory effects (Borg 1981). Verbeck et al. (1987) found that workers exposed to sound levels exceeding 80 dB(A) had increased blood pressure. Cohen et al. (1980) show that high aircraft noise exposure, in school, is associated with an increase in blood pressure. Other studies show an effect on levels of noradrenaline and adrenaline (Cavatorta et al. 1987) and in a study of aircraft-noise exposure in school children by Evans et al. (1995) noise induced an increase in epinephrine and norepinephrine levels. Some studies also indicate that noise should be included as a potential reproductive hazard (Baird 1985) and a risk factor for the unborn child (McDonald et al. 1986).

**Speech interference**

Speech interference is the specific situation where speech is masked by another sound. Masking is primarily an interaction between two simultaneous sounds where the masking effect is biggest within the frequencies of the masking sound. However, there is also a masking effect outside the background frequency area, mainly upwards in frequency. It has been shown that a low frequency sound masks a speech signal more than a high frequency sound (Gelfand 1981).

Another masking phenomenon is temporal masking where a signal is masked by another sound presented immediately before or after the signal (Moore 1997).

It is difficult to estimate the extent of speech interference from an A-weighted sound. However, the interference of speech communication is of special interest in school settings since the daily activities in the classroom are based on communication and concentration. Berg (1987) reports that pupils spend about 45% of the school day engaged in listening activities. Talk is used to organise
Background
classroom settings, to initiate and facilitate learning situations and to constitute the framework for classroom organisation and management (McSporran 1997).

Children generally have a less precise speech, a more limited vocabulary, and less familiarity with language rules than adults. Masking effects of noise may therefore be particularly critical both for the perception of children's speech and for the children's perception of speech. Exposure to high levels of noise during the period in which the children are acquiring speech, language, and listening skills may have effects on scholastic performance (DeJoy 1983). The average voice level for a teacher is, according to Pekkarinen and Viljanen (1990), 57 dB(A). In environments with a sound level exposure representing a typical sound level in an occupied classroom of 60 dB(A), as reported by Berg et al. (1996), and noise levels as high as 70 dB(A), as reported by Markides (1986) and Pekkarinen and Viljanen (1991), 75 - 85 dB(A), as measured by Ross (1982) and Finitzo (1988), or, to quote the series of measurements by Airey et al. (1998), 60 - 84 dB(A) in open-plan schools and 52 - 101 dB(A) in cellular classrooms, there is an obvious risk that the teacher's voice will not be clearly perceived. To determine if the pupils in a classroom can hear the necessary information there are six issues to be taken into consideration (Palmer 1997): the teacher's speech signal, which according to Crandell and Smaldino (1994) rarely achieves a satisfactory level throughout the day in a typical classroom, the noise in the classroom, the reverberation time, the distance from teacher to pupil, the pupil's hearing status, and the linguistic experience of the pupils.
**Behavioral effects of noise**

Two main types of noise effects have to be considered in classrooms: subjective responses, which will be discussed later, and behavioural effects, primarily performance.

In an early report Kryter (1950) claimed that there is no clear evidence that noise will impair performance in any work task, except in ways that may be explained by masking effects. Broadbent (1979) concluded that no clear effects of noise on performance have been demonstrated below 95 dB, a level that would be discouraged because of the risk of hearing impairment. Later studies have unequivocally pointed out the negative effects of noise on performance at much lower levels. Smith (1989, 1990) and Kjellberg and Landström (1994) give detailed recapitulations of studies on the effects of noise on performance and theories within the area.

Kjellberg and Landström (1994) point out critical physical noise characteristics for the performance effects of noise and claim, in contrast to Broadbent, that the critical sound level may be far below sound levels of risk of hearing damage. Noise at high frequencies may affect performance by competing for attention whereas low frequency noise also may have an effect of lowering alertness (Landström et al. 1987). Results by Hartley (1974) and Smith and Broadbent (1985) indicate that there is an effect of exposure time on performance and Smith (1985) found that intermittent noise impairs performance more often than continuous noise.

Moreover Smith (1990) concludes that the effects often depend on the nature of the task being performed. Kjellberg and Landström (1994) emphasize this point of view and add that the performance effects may be viewed as a result of masking, distraction, changes in arousal level and changes in strategies.

In the classroom masking of speech may be a serious problem and, as has been pointed out by Poulton (1977), so also may be masking of auditory cues which are of importance for tasks not primarily of an auditory nature.

Purcell and Thorne (1977) demonstrated that irrelevant speech and sudden changes in the noise in offices might interrupt a chain of thought and thus impair performance. Noise may temporarily distract our attention from the work task. The effect is likely to be larger in the case of a sudden, surprising noise event or a sudden change in its character.

Generally noise has been supposed to raise the arousal level (Landström et al. 1994) but there is reason to believe that repetitive or continuous noise in general
and, more particularly, low frequency noise sometimes makes people sleepy (Bohlin 1971; Landström et al. 1983).

In some cases the critical effect of noise may be on the strategy chosen for the performance of a task. A review of results from studies of these effects by Jones (1990) points out that we tend to get stuck in strategies close at hand when exposed to noise. The restriction of attention during noise exposure that has been found in several studies (see review by Smith 1991) may also be interpreted as a noise-induced change of strategy for intake of information.

Studies of the non-auditory effect of noise on children with a focus on school performance and cognitive development point out the adverse effects of noise on learning, school performance, memory and mood in the classrooms (Jones 1990; Crandell 1991; Pekkarinen and Viljainen 1991; Evans and Lepore 1993; Sanz et al. 1993; Hygge et al. 2003).

Noise exposure may affect pupils’ motivational state. Cohen et al. (1980) present data indicating reduced motivation in an achievement-related situation by showing that pupils from noisy schools are more likely to give up on difficult puzzles.

The cognitive effects of noise exposure on children have received most attention from researchers focusing on attentiveness, perception, memory and intellectual achievement (Evans and Lepore 1993). Teachers in noisy schools reported more concentration problems in students than did teachers in quieter schools (Ko 1979; Kryter 1985). In a study of young children (4-7 years) high ambient noise levels seemed to affect the child’s ability to sustain voluntary attention or to concentrate (Heft 1985).

Noise exposure seems to have little effect on children’s short-term memory, their working memory (Evans and Lepore 1993), and simple memory tasks. Hygge (1993) compared relatively easy and difficult memory tasks under quiet and noisy conditions. Only the difficult tasks were sensitive to noise exposure. A series of experiments investigating different noise sources and their effects on short-term memory shows that the learning process is more affected by verbal noise than by broad-band noise (Martin et al. 1988).

Bronzaft and McCarthy (1975) compared reading ability and sound pressure levels for schools close to railways. Students in classrooms with the highest sound levels were found to be late in their reading development. Moreover,
Cohen et al. (1980) have reported that air traffic noise can affect reading comprehension and mathematical proficiency.

Acute noise exposure seems to have little effect on reading and other intellectual activities whereas chronic noise exposure has been associated with reading deficits (Evans and Lepore 1993).

**Subjective reactions**

In an illustration of a psychological concept of annoyance, Guski (1997, 1999) presents the definition that it could represent feelings of irritation, discomfort, distress, frustration, or offence when noise interferes with someone's ongoing activities, thoughts or feelings (Passchier-Vermeer and Passchier 2000). Stallen (1999) describes the noise annoyance reaction as a phenomenon of "mind and mood", partly determined by acoustic factors. There are many non-acoustic factors identified as associated with annoyance. Molino (1979) defines a noise as annoying if exposure would cause the exposed individual or group of individuals to reduce the noise, or avoid or leave the noisy area if it were possible.

Annoyance is to be seen as a long-term dissatisfaction, disturbance or bother aggregated by the feelings mentioned above and triggered by, for example, the acoustic environment (Guski 1999).

Studies of adults show that annoyance, as well as negative effects on performance, increases with increasing sound level (Kryter 1985), tonal character of the noise and variability of the exposure (Holmberg 1997). The ear seems to recover during periods of lower sound levels so that the risk of hearing damage is smaller for intermittent noise than for continuous noise (Johansson et al. 1973). This theory of recovery is not applicable to the subjective reaction to noise. The discomfort and annoyance caused by a sound increases as the duration of a sound increases, at least up to durations of 100 s (Hiramatsu et al. 1976; Little et al. 1969). Weinstein (1982) claims that there is no adaptation to annoyance caused by noise in an environment with the same exposure day after day.

In a laboratory study by Kuowano et al. (1980) intermittent noise was perceived as more uncomfortable and annoying than continuous noise at the same level. Furthermore, Holmberg (1997) claims that differences in subjective responses seem to exist between high and low frequency exposures, broadband exposures and exposure time, being more critical for lower frequency exposures. There are several observations that point out that the A-weighting
underestimates the annoyance from LFN exposure (Kjellberg et al. 1984, Persson Waye and Björkman 1988, Leventhall 1980).

The majority of studies of noise annoyance have been carried out on adults. Research concerning subjective response to noise in school settings is rare and has mainly been focused on noise from road traffic, aircraft and railways. The results are in accordance with findings from annoyance research in adults, showing a relationship between high levels of transportation noise and annoyance (Haines and Stansfeldt, 2000). Results from studies concerning annoyance responses in communicative work settings indicate that sound level is of minor importance and that factors such as the informational content of the noise are more important (Kjellberg et al. 1996; Passchier-Vermeer and Passchier, 2000). A study by Kjellberg and Sköldström (1991) indicates speech to be more disturbing than meaningless random noise and Landström et al. (2002) found talk to be more disturbing than meaningless noise in connection with more difficult verbal tasks (Landström et al. 2002).

When examining subjective responses to noise in classrooms, studies of perception of classroom noise in Denmark (Bredo 2000) report that 19 % of the responding children were frequently annoyed by noise during school lessons and 62 % were sometimes annoyed by noise. The annoying noise was laughter, talking and noise from movement of chairs and tables.

**Non-acoustic factors**

The correlation between sound level and annoyance is rather poor (Kjellberg et al. 1996; Landström et al. 1990). About one third of the variance in annoyance reactions can be explained by the variance in acoustic features, another third by the variance in personal or social variables (Guski 1999).

Individual characteristics of importance in the noise reaction may be permanent, such as hearing impairment (Aniansson and Björkman 1983), or temporary, such as sensitivity to noise (Jones and Davies 1984). Kjellberg et al. (1996) found that noise annoyance decreased when a work task was considered to be more engaging. Kjellberg and Sköldström (1991) report higher tolerance to noise annoyance in subjects working on a simpler work task than in subjects working on more complex tasks. Furthermore, subjects were more annoyed by talk than pink noise of the same level during a reading task (Kjellberg and Sköldström 1991).
In the area of stress research it is shown that the feeling of stress caused by an event is higher if the event is unpredictable and uncontrollable (Thompson 1981). There is support for this concerning noise stimuli (Kohfeld and Goedcke 1978; Kjellberg et al. 1996; Flynn et al. 1996).

Attitude to a noise source is proven to be of importance to the reaction. McKenell (1980) found, for example, that persons who were favourably disposed to the Concorde project were less annoyed by the noise from the aircraft.

Assessing subjective response to noise

A recent study by the community response to noise team of ICBEN (The International Commission on the Biological Effects of Noise) set the goal of devising high-quality survey questions that would yield internationally comparable ways of measuring overall reactions to noise sources (J. M. Fields et al. 2001). This, it was hoped, would solve the problem of interference in the accumulation of knowledge of factors that affect the responses of different communities to noise due to differences in the wording of survey questions and to the weakness of some of the questions.

A simple rating scale as a subjective measurement of annoyance has been developed and adapted in different studies (Landström et al. 1994; Landström et al. 1996; Kjellberg et al. 1996; Holmberg et al. 1997). Direct ratings of annoyance caused by noise are mostly used for the measurement of subjective noise effects. Another type of subjective measurement is one which measures affect, fatigue and mood. The possible relation of these to noise is evaluated by analysing the relation between such measurements and noise exposure. Many adjective checklists have been developed for such purposes (Bohlin and Kjellberg 1973; Kjellberg and Bohlin 1974; Russel 1980; Sjöberg et al. 1979). Russel (1980), has suggested that these states may be described by a two-dimensional circular structure divided into eight sectors, a circumplex model, to represent affective states. Pleasantness and arousal are assumed to be the two basic dimensions; other affective dimensions are represented by different sectors. Russel and Pratt (1980) used this model to describe affective qualities attributed to environments. None of the existing instruments have been developed for use with children or for the classroom situation. This application puts special demands on the choice of scales in the instrument and account must be taken of children’s vocabulary.
AIMS

The overall purpose of this thesis has been to increase knowledge of noise exposure in classrooms and the subjective response among pupils, and also to identify factors of particular relevance to the assessment of negative noise effects in the classroom.

The specific aims have been:

- To display noise levels in classrooms and how these levels relate to external noise, subject, number of pupils in a class, and grade.
- To evaluate annoyance and other subjective responses to noise in pupils.
- To identify sound sources in the classroom environment that might be considered critical on the basis of subjective responses.
- To develop an adjective checklist to be used to identify negative effects of noise on aspects of the pupil’s mood that are relevant to his/her work.
- To investigate whether background noise in Swedish elementary schools is to be considered LFN and to test whether pupils exposed to audible LFN at high levels are more annoyed than pupils exposed to LFN at low level.
Methods

The work of this thesis is presented in five separate articles considering different aspects of sound exposure and adverse effects experienced by pupils in school. Papers I (*Annoyance and effects on work from environmental noise at school*), II (*Low frequency noise and annoyance in classrooms*) and IV (*Sound levels in classrooms and effects on self-reported mood among school children*) are field studies which focus on how pupils experience the sound in their working environment, whether there are any adverse effects and whether these have any relationship to sound exposure in the classroom. Paper III (*Evaluating effects of the classroom environment: Development of an instrument for the measurement of self reported mood among school children*) is focused on developing a mood-rating instrument to identify effects of noise and other aspects of the classroom environment as a complement to existing rating scales. Paper V (*Environmental noise at school and effects on performance and mood*) is a laboratory study where critical sound environmental factors in school and effects on annoyance are studied.

**Paper I**

The aim of paper I is to look into how pupils rate the annoyance of noise and its effects on their schoolwork, to find out what source of sound pupils find to be the most annoying during their work and to find whether there are any differences in the rate of annoyance, experienced effects on schoolwork and the most annoying sound source according to gender and age.

The equivalent sound levels ($L_{eq(A)}$) were measured during the lesson and the pupils and teachers filled out a questionnaire immediately afterwards. The pupils were asked to rate the annoyance caused to them by the noise during the measurement period. The pupils were also asked to state how the sound environment affected their work and which the most annoying noise source was.
A question about the pupil's hearing status was added to ensure the identification of any pupil with a hearing impairment. The teacher in each class was asked their opinion on how their pupils were annoyed by the noise.

**Paper II**

The aims of this study were to investigate whether background noise in Swedish elementary schools is to be considered LFN, and also to test whether pupils exposed to audible LFN at high levels are more annoyed than pupils exposed to LFN at lower levels.

A-weighted and C-weighted levels were measured and the classrooms were categorised as low LFN level exposure or high LFN exposure according to the $L_{Ceq} - L_{Leq}$ difference. The pupils working in the 22 classrooms were asked to rate their annoyance.

**Paper III**

The aim of this study was to develop a mood-rating instrument to identify the effects of noise and other aspects of the classroom environment which are of relevance to the children's scholastic performance.

For the construction of the word list, words describing states of relevance to educational efficiency were picked from Swedish mood adjective checklists (Bohlin and Kjellberg 1973; Kjellberg and Bohlin 1974; Sjöberg et al. 1979) and a synonym dictionary. Two groups of pupil were asked to estimate to what extent each word described how they felt at the end of the lesson. The answers from group 1 were examined, and words with non-response rates higher than 10 per cent were excluded. To reduce ratings to a smaller number of underlying dimensions, the ratings were subjected to a principal factor analysis. The rotated structure provided the basis for exclusion of words that did not fit into the model.

For cross-validation of the results in group 1 the same analysis was carried out in group 2. Finally the whole material taken together was subjected to the analysis for a final revision of the scales. Factor scores were calculated and correlated with unweighted means of ratings of subscales of the respective factor. A high correlation indicates that little is lost by using simpler mean calculation.
**Methods**

**Paper IV**

The first aim of paper IV is to present an investigation of the noise levels recorded in classrooms and how these levels are affected by the variables external noise, type of education, number of pupils, and grade of education. The second aim is to display possible relations between three aspects of the children’s mood - annoyance, task orientation, and inattentiveness - and five different measures of sound level.

This field study presents an investigation of recorded sound levels and relations between sound level measurements and aspects of children’s rated mood.

The background sound and activity sound within the audible range (20 – 20 000 Hz) in 24 classrooms was recorded. The analyses of the recordings result in five variables: A-weighted equivalent sound level for empty classroom and during lesson and also three L_n–percentiles during lesson.

At the end of the lesson the pupils were asked to rate their annoyance, task orientation and inattentiveness.

**Paper V**

The aim of this study was to investigate the effects of noise from different prominent noise sources in classroom environments. Speech, ventilation noise, traffic noise and building noise are included in the study. The effects from these specific noise sources are compared with the effects from a complex noise exposure including all these types of specific noises. The effects are analysed during exposure to different noise levels.

**Environments**

Study I was carried out in two representative schools in Sweden. All the measurements were made under similar conditions, with the class sitting down in a classroom working on mathematics.

Studies II and IV were extended to include three representative schools in Sweden. The subjects of the ongoing lessons were of two types: in 11 classrooms the ongoing lessons were mathematics and in 13 classrooms language studies. In the mathematics lesson the pupils were solving arithmetical problems and the language lessons included reading and writing.

Measurements were made under similar conditions, with the classes sitting down in a classroom working individually.
Methods

In study III, pupils were chosen from the 7th, 8th and 9th grades with an age range of 13 to 16 years from a wide range of schools and lessons in order to capture a wide range of mood states.

The experiment in study V was carried out in a sound-attenuated chamber (3.2 x 8.0 m). The chamber was equipped with six tables suited for two subjects each. The tables were separated by a partition wall.

Control of the sound pressure level was carried out with a sound level meter (Brüel & Kjær 2237) and a 0.5” microphone (Brüel & Kjær 4137). Measurements of the background sound levels were made with the same equipment. The background sound level in the chamber was 12-15 dB(A). The ventilation was forced during the breaks between test sessions but was turned off during the tests. The temperature in the chamber during the test periods was 19-21°C.

Participants

In study I twelve classes with a total of 216 pupils took part. One hundred were from the 7th grade (13 years old), 54 from the 8th grade (14 years old) and 62 from the 9th grade (15 years old). There were 112 girls and 104 boys. The number of pupils in each class was 16-24 for all the classes except one, which had only 8 pupils (group 10). Twelve teachers took part in the study, 8 women and 4 men.

In study II 337 pupils, working in 22 classrooms, distributed between three representative schools, participated.

In study III two groups of pupils were used. Group 1 consisted of 280 pupils, 150 girls and 130 boys. Group 2 consisted of 443 pupils, 218 girls and 225 boys.

The number of pupils participating in the study IV was 442. The number of pupils in each class was on average 17 (SD=4.8). Among the participants, 34 of the pupils were 12 years old, 161 were 13, 115 were 14 and 133 of the pupils were 15.

Finally, 48 students aged 16-17 in the first grade of the Swedish upper secondary school taking natural science and social science course programmes were recruited to participate in study V. The students were randomly assigned to 4 groups with different noise exposure sequences, six boys and six girls in each group except for one group that had four boys and eight girls. The hearing status of the subjects was tested according to the ISO standard on screening audiometry (ISO 8253-1).
Methods

Analysis of exposure

In the first study, paper I, the equivalent sound levels ($L_{eq(A)}$) were measured with an integrating sound level meter (Larson Davis model 712).

In studies II and IV the documentation of the sound environment was extended to recordings of background sound and activity sound. The background recordings were conducted with the ventilation systems turned on and with normal activity in the school building and the surroundings but with no people in the investigated classrooms. For the activity sound, the properties were the same as for the background but the recordings were made in the middle of a lesson. The sound within the audible range (20 - 20 000 Hz) in each classroom was recorded using a sound level meter (Brüel & Kjær 2237) with a 1/2" microphone (Brüel & Kjær 4189) and a digital tape recorder (TEAK DA-P20). The recordings were analysed using a real time analyser (Brüel & Kjær PULSE). The A-weighted equivalent sound level ($L_{Aeq}$) and Ln percentile level for each recording were calculated. Ln percentile is a value that represents the sound pressure level exceeded n % of the time (n=10, 50 and 90). The analyses of the recordings result in five variables - the A-weighted equivalent sound level for empty classroom and for lesson ($L_{Aeq(empty)}$ and $L_{Aeq(lesson)}$) as well as three Ln- percentiles during the lesson ($L_{n10}$, $L_{n50}$, and $L_{n90}$). The background recordings were made for 10 minutes. In all three studies - I, III and IV - lesson recordings were made for 20 minutes in the middle of the 40-minute lesson. The first and last ten minutes of the lesson were excluded because of the starting and ending procedures.

The background sound level recordings in study II were analysed according to A-weighted and C-weighted levels. The $L_{Ceq} - L_{Aeq}$ difference was calculated from the equivalent sound levels. The classrooms with an $L_{Ceq} - L_{Aeq} < 15$ dB were categorised as low LFN level exposure and classrooms with $L_{Ceq} - L_{Aeq} > 20$ dB were categorised as high LFN exposure. For the purposes of the study A-weighted and C-weighted levels were calculated for a limited frequency range, i.e. 63-20 kHz. This was done in order to obtain an $L_{Ceq} - L_{Aeq}$ level difference based on the frequency range in which the sound pressure level exceeded the hearing threshold level. The result is an $L_{Ceq} - L_{Aeq}$ difference based on the frequency range with levels above the hearing threshold level for frequencies in the lower part of the sound spectra, $L_{Ceq(63-20kHz)} - L_{Aeq(63-20kHz)}$. The classrooms with an $L_{Ceq(63-20kHz)} - L_{Aeq(63-20kHz)} < 10$ dB were categorised as low LFN level exposure and
classrooms with $L_{\text{Ceq}(63-20\,\text{kHz})} - L_{\text{Aeq}(63-20\,\text{kHz})} > 13$ dB were categorised as high LFN exposure.

In all measurements in papers I, II and IV, the microphone was placed in a representative, asymmetrically situated position in the classroom corresponding to the ear height of the pupils in order to measure the perceived noise.

In study V the subjects were exposed to five different sound sources of relevance to the school environment: ventilation, road traffic, irrelevant speech, structure-borne sounds and a complex classroom sound containing all four components. A homogenous sound field was generated from a hard disc audio system (Instant Replay 360 systems). The sound signal was fed through a power amplifier (Yamaha P 1600) to ten speakers (JPW mini monitor) placed symmetrically in the ceiling generating a sound field in the chamber with a range $\pm 1$ dB of the exposure level induced. The pupils were seated at the same position during all four sessions to minimize differences between test occasions.

The sound sources were presented at four different levels for the subjects (35, 40, 55 and 65 dB).

Effects

The annoyance-rating scale used in studies I and V (Fig. 1) was the same type as has been used in previous noise studies (Landström et al. 1990; Holmberg 1997). The scale is developed from an ordinary visual analogue scale. The pupils were not trained to use this scale but they were given instructions on how to use it. They were asked to put a mark anywhere along the 100 mm scale, not necessarily on a label, but in the position that best represented their perceived annoyance during work in the last 20-minute period. This rating scale was developed for adults. According to theories in social science on how children understand scales and theory of sets it is reasonable to assume that children in these ages have sufficient knowledge to use this type of scale. The rated annoyance was measured in mm from the left end of the scale and assumed to be interval data.
Methods

Additionally in study I the pupils were asked to state how the sound environment affected their work in a multiple choice question. Five alternatives were given from "Made it much easier" to "Made it much harder". Finally the questionnaire asked which was the most annoying sound source. A question about the pupil’s hearing status was added to ensure the identification of any pupils with a hearing impairment. The teacher in each class was asked to fill in a questionnaire ascertaining their opinion of how the pupils were annoyed by the noise.

In study II the pupils were asked to report their annoyance in a multiple-choice question. Five alternatives were given: "Not at all annoyed", "Somewhat annoyed", "Quite annoyed", "Much annoyed" and "Very much annoyed".

The instrument used for evaluation of adverse effects of the sound environment in studies IV and V was based on twelve words describing two unipolar factors orientation (TO) and inattentiveness (IA). This method and its development are described in paper III.

In paper V the pupils worked with a simple mental arithmetic operations test. This was done to evaluate the effect of different sound sources and levels on aspects of school performance.

The scale used for subjective ratings of performance in study V was designed as a visual analogue scale where the subjects rate their performance as a percentage of maximum performance. The scale used for subjective ratings of effort is of the same type as the annoyance rating scale.

Figure 1. The annoyance rating scale.
Statistics

**Paper I**

To find any differences in annoyance ratings between groups in the sample, a T-test for independent samples was used. A two-tailed T-test was used to display the difference between sound level dependence on the pupil’s perceived annoyance and on the teacher’s rating of the pupil’s annoyance. To display differences according to gender or grade for the question of how the pupils estimated the effect of the sound environment on their work a chi-square test was used.

To examine the relation between noise levels, annoyance and performance, Pearson correlation coefficients were calculated.

**Paper II**

To test the hypothesis that pupils working in classrooms with high LFN levels are reported to be more annoyed than pupils working in classrooms with low LFN levels, a Mann-Whitney U-test was used. The same statistical tool was used to provide sufficient evidence that there was no difference between the groups in \( L_{Aeq} \). The level of significance was chosen to be \( p<0.05 \).

**Paper III**

The ratings of the 45-item questionnaire from group 1 were examined, and words with a non-response rate higher than 10 per cent were excluded. To reduce ratings to a smaller number of underlying dimensions, the ratings were subjected to a principal factor analysis and the resulting factors were obliquely rotated using the oblimin criterion. The rotated structure provided the basis for exclusion of words that did not fit into the model. The scree criterion was used to determine the number of factors.

The main criteria for a word to be excluded were low loadings in all factors or high loadings in more than one factor. Finally some words were excluded from the model to give roughly the same number of words in each factor. Cronbach’s alpha was used as an indicator of the reliability of the resulting scales.

For cross-validation of the results in group 1 the same analysis was carried out in group 2. Finally the whole material taken together was subjected to analysis in order to make some final revisions of the scales.
Factor scores were calculated and correlated with unweighted means of ratings of subscales of the respective factor. A high correlation indicates that little is lost by using the simpler mean calculation.

**Paper IV**

The Pearson's correlation coefficients between sound level and each of the other variables (background sound level, type of education, number of pupils and grade of education) were estimated and the null hypothesis of no correlation was tested. A multiple linear regression model was fitted in order to describe the simultaneous dependence between the explanatory variables and the sound level. To test the null hypothesis of no difference between the sound levels in different schools, a one-way ANOVA was used. The null hypothesis of no mean difference in sound level according to subject was tested in a t-test. To test the null hypothesis of no difference in sound level according to grade or class size, a regression analysis was performed. A multi-regression model was fitted in order to give a simultaneous explanation of the dependence between the sound level and the explanatory variables class size, background sound level, grade, subject and school.

Each of the five sound variables is grouped in two categories: high-level exposure (HL) and low-level exposure (LL). The nine groups with the lowest levels were categorised as “LL” and the nine groups with the highest levels were categorised as “HL”. The two categories in each of these six variables are compared according to annoyance rating (AR), task orientation (TO) and inattentiveness (IA). To test the null hypothesis of no difference in AR, TO or IA between the HL and LL exposure groups, a Mann-Whitney U-test was used.
Methods

Paper V

Annoyance, effort, performance, TO, and IA ratings were analysed with a repeated measurement ANOVA. Twenty-six of the subjects had missing values in at least one of the cells. The distribution of missing values is presented in table 1. Missing values were imputed using an EM (expectation-maximization) method (SPSS software).

<table>
<thead>
<tr>
<th>Number of missing values</th>
<th>Number of subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1 - 10)</td>
<td>(14)</td>
</tr>
<tr>
<td>1 – 25</td>
<td>19</td>
</tr>
<tr>
<td>26 – 50</td>
<td>2</td>
</tr>
<tr>
<td>51 – 75</td>
<td>1</td>
</tr>
<tr>
<td>76 – 100</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1. The distribution of missing values for the subjects.
RESULTS

Paper I

Table 2 presents the sound levels and rated annoyance for each class and Table 3 shows the total sound level and mean annoyance for each grade. Despite the range of 11 dB, the average sound levels for the grades were almost equal (Table 3). The difference in mean dB(A) was not significant. For the pupils in the 7th grade the mean annoyance corresponds to the verbal definition “Somewhat annoying - Rather annoying”. The mean ratings in the 8th and 9th grades correspond to a lower rating, the verbal definition “Somewhat annoying”.

<table>
<thead>
<tr>
<th>Group</th>
<th>Grade</th>
<th>( L_{eq(A)} )</th>
<th>Annoyance (SD)</th>
<th>Annoyance (SD) ( L_{eq(A)} )</th>
<th>Annoyance (SD) ( L_{eq(A)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Boys</td>
<td>Girls</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>58</td>
<td>29 (16)</td>
<td>21 (20)</td>
<td>31 (15)</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>61</td>
<td>29 (19)</td>
<td>40 (17)</td>
<td>17 (14)</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>62</td>
<td>40 (17)</td>
<td>36 (17)</td>
<td>44 (16)</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>62</td>
<td>19 (12)</td>
<td>21 (10)</td>
<td>18 (14)</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>63</td>
<td>22 (14)</td>
<td>23 (8)</td>
<td>21 (19)</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>64</td>
<td>32 (19)</td>
<td>30 (18)</td>
<td>34 (21)</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>65</td>
<td>28 (32)</td>
<td>34 (39)</td>
<td>21 (24)</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>65</td>
<td>18 (20)</td>
<td>18 (24)</td>
<td>18 (17)</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>66</td>
<td>37 (21)</td>
<td>34 (22)</td>
<td>40 (21)</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
<td>66</td>
<td>33 (21)</td>
<td>32 (19)</td>
<td>33 (29)</td>
</tr>
<tr>
<td>11</td>
<td>9</td>
<td>69</td>
<td>13 (12)</td>
<td>16 (12)</td>
<td>11 (7)</td>
</tr>
<tr>
<td>12</td>
<td>7</td>
<td>69</td>
<td>45 (23)</td>
<td>41 (23)</td>
<td>52 (21)</td>
</tr>
</tbody>
</table>

Table 2. Rated annoyance 0-100 scale and \( L_{eq(A)} \) for each class, boys and girls. The groups are sorted by \( L_{eq(A)} \). The standard deviation is given in parentheses.
Results

<table>
<thead>
<tr>
<th>Grade</th>
<th>( L_{eq(A)} )</th>
<th>Annoyance (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>64</td>
<td>34 (20)</td>
</tr>
<tr>
<td>8</td>
<td>65</td>
<td>26 (20)</td>
</tr>
<tr>
<td>9</td>
<td>64</td>
<td>25 (22)</td>
</tr>
<tr>
<td>total</td>
<td>64</td>
<td>29 (21)</td>
</tr>
</tbody>
</table>

Table 3. Equivalent sound level (arithmetic mean), mean annoyance on a 0-100 scale, total for all grades and for each grade. The standard deviation is given in parentheses.

No significant difference in annoyance was shown between boys and girls. There was a difference \((p<0.01)\) between the annoyance of the pupils in the 7th grade and that of the ones in grades 8 and 9 and the younger pupils were more annoyed. The difference in rated annoyance, shown in table 2, was 8 mm for grade 8 compared with grade 7 and 9 mm for grade 9 compared to grade 7.

No differences, either between boys and girls or between the three grades, were found regarding how the pupils claimed that the sound environment affected their work.

The pupils claimed that the most annoying sound sources were chatter in the classroom and scraping sounds from tables and chairs. There were no differences between boys and girls or between the different grades regarding the ranking of the sources.

There was no support from this material for a correlation between sound level and perceived annoyance nor between sound level and rated effect of noise on the pupils’ schoolwork. The correlation between the annoyance and rated effect of noise on the pupils’ schoolwork \((r=0.53)\) was significant \((p<0.01)\).

The teachers’ estimations of the pupils’ annoyance were correlated to \( L_{eq(A)} \) \((r=0.63 \ p=0.03)\).

The difference between the pupils’ perceived annoyance as a function of A-weighted sound level and the teacher’s rating of the pupils annoyance as a function of A-weighted sound level was significant \((p<0.05 \ t=2.34 \ df=224)\).

Ten of the twelve teachers claimed that the existing sound environment had a negative effect on the pupils’ work. All the teachers claimed that the most annoying sound source for the pupils was chatter in the classroom and scraping from tables and chairs.
Results

Paper II

Eight of 22 classrooms had an $L_{Ceq} - L_{Aeq}$ difference of 15 dB or below. These classrooms are categorised as low LFN exposure. Nine classrooms had an $L_{Ceq} - L_{Aeq}$ difference of 20 dB or above. These classrooms are categorised as high LFN exposure. The arithmetical means of $L_{Aeq}$ for the LFN exposure groups are 39 dB(A) for the low LFN exposure and 38 dB(A) for the high LFN. There was no statistically significant difference in $L_{Aeq}$ between the low LFN exposure groups and the high LFN exposure groups ($Z = -.93$, $p > .05$).

Figure 2 shows the distribution of pupils’ reported annoyance during the lesson. The comparison of reported annoyance between the high and low LFN-exposed groups, based on an $L_{Ceq} - L_{Aeq}$ difference to identify LFN, shows that there was no difference in rated annoyance between these groups ($Z = -.84$, $p > .05$).

![Figure 2: The distribution of reported annoyance between the high and low LFN-exposed groups, with an $L_{Ceq} - L_{Aeq}$ difference used to identify LFN.](image)

The median, max and mean of sound pressure levels in 1/3-octave bands for the 22 classrooms are shown in figure 3. The spectra were related to the normal hearing threshold (ISO 1985). The analysis shows that for the frequencies 25, 31, 40 and 50 Hz all sound levels were close to or below the hearing threshold level.
Results

Figure 3: Median, maximum and minimum of sound pressure level in 1/3-octave bands for the background noise in the 22 classrooms. The unbroken line shows the normal hearing threshold (ISO 226-1 1985).

A second analysis, based on the frequency range in which the sound pressure level exceeded the hearing threshold level $L_{Ceq(63-20kHz)} - L_{Aeq(63-20kHz)}$, was made. Nine classrooms that had an $L_{Ceq(63-20kHz)} - L_{Aeq(63-20kHz)}$ difference of 10 dB or below were categorised as LFN exposures. Ten classrooms that had an $L_{Ceq(63-20kHz)} - L_{Aeq(63-20kHz)}$ difference of 13 dB or above were categorised as high LFN exposures.

The comparison of the reported annoyance between the high and low LFN-exposed pupils, based on use of an $L_{Ceq(63-20kHz)} - L_{Aeq(63-20kHz)}$ difference to identify LFN, shows that there was no difference in rated annoyance between the high LFN exposed groups and the low LFN exposed groups ($Z= -.57$, $p > .05$). The arithmetical means of the $L_{Aeq(63-20kHz)}$ for the LFN exposure groups is 39 dB(A) for the low LFN exposure and 37 dB(A) for the high LFN exposure.
Paper III

Group 1
Thirteen items had a non-response rate higher than 10 per cent and were excluded. The scree plot from the factor analysis of the remaining 32 items indicated that three factors should be extracted (another three factors had eigen values between 1.0 and 1.4). The first factor described the degree of task orientation. The items with salient loadings in the second factor appear to describe inattentiveness, and all items had a negative loading in the first factor. The correlation between the two factors was, however, moderate (-0.26). Four items, expressing feelings of calmness and relaxation (calm, relaxed, tranquil), had their highest loading in the third factor. These three factors explained 49.8 per cent of the variance. The third factor was judged as less relevant in the following analyses; the four items belonging to the third factor were therefore excluded.

Furthermore two factor solutions of the remaining items lead to the exclusion of an additional 11 items on account of too low or too high loadings in both factors. In the final analysis of the remaining seventeen adjective scales the two factors explained 50.1 per cent of the variance. Factor 1, task orientation, contained nine items describing a dimension of concentration, interest and focus. All loadings were greater than 0.63. Factor 2, inattentiveness, included eight items describing inattentiveness, restlessness and confusion. All loadings were above 0.50 except for one subscale, under stress, which had a loading of 0.40 but had a zero loading in factor 1 and was kept to get a better balanced model. The correlation between the two factors was -.28.

Group 2
The two-factor solution of the 17 items in group 2 explained 48.0 per cent of the variance and gave a result very similar to the one obtained in group 1. The correlation between the two factors was -0.26.

Unconcentrated and inattentive had high loading in both factors in the analyses of both groups and should therefore be excluded, thus leaving six items representing factor 2. To achieve the same number of items in factor 1, the three items having the lowest loadings in both analyses were also excluded (wide-awake, composed, careful).
Finally, an analysis based on the whole material was made of the remaining twelve items (Table 4). This final model explained 53.5 per cent of the variance in the whole material. Cronbach’s alpha was 0.83 for both factors. The correlation between the two factors was -0.21.

The correlation between the factor score and the unweighted mean of ratings of subscales was $r= 0.96$ for factor 1 and $r= 0.99$ for factor 2.

<table>
<thead>
<tr>
<th></th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrated</td>
<td>(Koncentrerad)</td>
<td>0.81</td>
</tr>
<tr>
<td>Diligent</td>
<td>(Flitig)</td>
<td>0.80</td>
</tr>
<tr>
<td>Effective</td>
<td>(Effektiv)</td>
<td>0.79</td>
</tr>
<tr>
<td>Interested</td>
<td>(Intresserad)</td>
<td>0.79</td>
</tr>
<tr>
<td>Attentive</td>
<td>(Uppmärksam)</td>
<td>0.73</td>
</tr>
<tr>
<td>Inspired</td>
<td>(Inspirerad)</td>
<td>0.73</td>
</tr>
<tr>
<td>Confused</td>
<td>(Virrig)</td>
<td>-0.25</td>
</tr>
<tr>
<td>Boisterous</td>
<td>(Stojig)</td>
<td></td>
</tr>
<tr>
<td>Exhilarated</td>
<td>(Uppspelt)</td>
<td></td>
</tr>
<tr>
<td>Absent-minded</td>
<td>(Tankspridd)</td>
<td>-0.28</td>
</tr>
<tr>
<td>Restless</td>
<td>(Rastlös)</td>
<td>-0.34</td>
</tr>
<tr>
<td>Under stress</td>
<td>(Stressad)</td>
<td></td>
</tr>
</tbody>
</table>

*Table 4. Factor structure for the twelve selected items from an analysis of both groups taken together. Loadings <0.2 are not shown.*
Results

Paper IV

This field study presents an investigation of recorded sound levels in 24 classrooms and relations between sound level measurements and aspects of children's rated annoyance, task orientation (TO) and inattentiveness (IA). The results of the investigation first include an overview of the sound levels recorded in the classrooms and the way in which these levels are affected by the variables: external noise, type of education, number of pupils and grade of education. Two groups were excluded from the material because the pupils were performing a test.

Sound levels

Table 5 gives the mean equivalent background sound level and mean equivalent activity sound levels in the different schools investigated. No significant difference between the activity sound levels in different schools was found (p=0.66 using one-way ANOVA). School 1 had a lower background sound level than the other schools (p< 0.01 using one-way ANOVA). The equivalent background sound level was above 40 dB(A) in 8 classrooms and the equivalent activity sound level exceeded 60 dB(A) in 12 of 24 classrooms. In 14 classrooms the level exceeded 55dB(A)eq for 50% of the time and in four classrooms for 90% of the time.

<table>
<thead>
<tr>
<th></th>
<th>School 1</th>
<th></th>
<th>School 2</th>
<th></th>
<th>School 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. classes</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Activity sound levels in dB(A)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>55.6</td>
<td>58.1</td>
<td>57.9</td>
<td>57.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>5.1</td>
<td>6.7</td>
<td>5.7</td>
<td>5.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>46.8-62.1</td>
<td>49.0-68.3</td>
<td>50.9-66.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Background sound levels in dB(A)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>35.1</td>
<td>39.3</td>
<td>38.0</td>
<td>38.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>2.3</td>
<td>2.0</td>
<td>1.2</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>32.9-40.1</td>
<td>36.4-42.3</td>
<td>36.4-39.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5. Arithmetic mean sound exposure levels in classrooms investigated.*
Results

Classroom sound levels and background sound levels
The correlation between activity sound level and background sound levels was estimated using the recorded classroom’s activity sound levels and the recorded sound levels in the empty classrooms. According to Figure 4 the mean values of the activity sound level increase with higher background sound levels. The estimated regression line is drawn to clarify the dependence. A 10 dB increase in background sound level corresponds to an 8-9 dB increase in activity sound level. The correlation is not significant, however (r=0.28 p=0.18).

![Graph showing the relationship between background sound level and activity sound level.](image)

*Figure 4. Activity sound levels in the classrooms as a function of the background sound levels.*

Sound levels and type of subject
The relation between classroom noise levels and type of education was tested by comparing the noise levels during mathematics lessons (M 54.9 dB(A), Sd 4.2 dB(A) n=13) and the noise levels during language lessons (M 59.6 dB(A), Sd 6.2 dB(A) n=13). According to a t-test, the mean-difference differs significantly from zero (p = 0.01).
Results

Noise levels and number of pupils

The correlation between classroom noise levels and number of pupils was estimated. The result is shown in Figure 5. There is an indication of increasing noise level in the classrooms with an increasing number of pupils. The estimated regression line is drawn to clarify the dependence. According to this a doubling of the number of pupils in a class gives a rise in activity sound level of 3 dB ($r = 0.40 \ p = 0.05$).

![Figure 5. Noise levels in the classrooms as a function of the number of pupils.](image)

Sound levels and grade of education

The relation between classroom noise levels and grade of education was tested by comparing the noise levels for the pupils at the grades 6 (M 57.6 dB(A), Sd 6.3 dB(A) n = 2), 7 (M 58.3 dB(A), Sd 5.8 dB(A) n = 10), 8 (M 58.9 dB(A), Sd 7.7 dB(A) n = 5) and 9 (M 55.2 dB(A), Sd 4.9 dB(A) n = 9). There is no evidence of any difference in sound level according to grade ($F = 3.0 \ p = 0.07$).
A multiple comparison

A multiple regression model was fitted in order to give a simultaneous explanation of the dependence between the noise level and the explanatory variables. The result is shown in table 6. When all five variables are fitted in a model, a positive relation to background sound level and a negative relation to age are significant. If a stepwise selection procedure is used when entering the variables into the regression equation, where the first considered variable to be entered is the one with the largest correlation with the dependent variable, the result is that all variables are excluded except subject (t=2.80 p=0.01)

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef.</th>
<th>SE Coef.</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>35.29</td>
<td>13.64</td>
<td>2.59</td>
<td>.02</td>
</tr>
<tr>
<td>Subject</td>
<td>2.61</td>
<td>1.83</td>
<td>1.43</td>
<td>ns</td>
</tr>
<tr>
<td>Age</td>
<td>-2.49</td>
<td>.99</td>
<td>-2.51</td>
<td>.02</td>
</tr>
<tr>
<td>Students/ class</td>
<td>.40</td>
<td>.191</td>
<td>2.07</td>
<td>.05</td>
</tr>
<tr>
<td>Background level</td>
<td>.82</td>
<td>.388</td>
<td>2.12</td>
<td>.05</td>
</tr>
<tr>
<td>School</td>
<td>.42</td>
<td>1.11</td>
<td>.377</td>
<td>ns</td>
</tr>
</tbody>
</table>

*Note.* Adjusted $R^2$ is 0.35.

*Table 6. Result of the multiple regression analysis.*
Results

Effect

The mean A-weighted equivalent sound levels for empty classroom ($L_{Aeq(Empty)}$) during class ($L_{Aeq(Class)}$) and Ln-percentiles during class ($Ln_{10}$, $Ln_{50}$ and $Ln_{90}$) in the high level exposure (HL) and low level exposure (LL) groups are presented in table 7.

There were high correlations between the $L_{Aeq(Class)}$, $Ln_{10}$, $Ln_{50}$, and $Ln_{90}$ in this material ($r = .81 - .98$) and only a weak correlation between $L_{Aeq(Empty)}$ and $Ln_{10}$ and $Ln_{90}$ ($r = .46$ and $r = .43$). Table 7 displays the mean values of the annoyance ratings (AR) and ratings of the indices task orientation (TO) and inattentiveness (IA).

<table>
<thead>
<tr>
<th></th>
<th>Low level Mean ratings</th>
<th>High level Mean ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dB(A)</td>
<td>TO   IA   AR</td>
</tr>
<tr>
<td>$L(A)_{eq}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Empty)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M Range</td>
<td>35</td>
<td>2.9  2.1  2.0</td>
</tr>
<tr>
<td></td>
<td>33-37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>(Class)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M Range</td>
<td>52</td>
<td>2.8  2.8  2.3</td>
</tr>
<tr>
<td></td>
<td>47-53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>$Ln_{90}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M Range</td>
<td>42</td>
<td>2.9  2.1  2.0</td>
</tr>
<tr>
<td></td>
<td>36-44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>$Ln_{50}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M Range</td>
<td>49</td>
<td>3.0  2.1  2.0</td>
</tr>
<tr>
<td></td>
<td>43-51</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>$Ln_{10}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M Range</td>
<td>57</td>
<td>2.9  2.1  2.1</td>
</tr>
<tr>
<td></td>
<td>52-58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Mean equivalent sound levels. Standard deviation and mean task orientation (TO), inattentiveness (IA), and annoyance (AR) ratings for the two groups. Low level and high level exposure.

The statistical analysis of the material did not support the assumption of a difference in rated annoyance, task orientation and inattentiveness between the LL-exposure group and the HL-exposure group ($z = (-1.5) - (-.24)$, $p > .05$).
Results

Paper V

Mean ratings of annoyance, effort, performance, TO and IA to the twenty sound-exposure combinations, five sources and four levels, are presented in table 1.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Level</th>
<th>Ventilation</th>
<th>Speech</th>
<th>Structure</th>
<th>Traffic</th>
<th>Classroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annoyance (mm)</td>
<td>35</td>
<td>28</td>
<td>35</td>
<td>30</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>32</td>
<td>48</td>
<td>49</td>
<td>36</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>46</td>
<td>58</td>
<td>62</td>
<td>45</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>59</td>
<td>58</td>
<td>63</td>
<td>59</td>
<td>56</td>
</tr>
<tr>
<td>Effort (mm)</td>
<td>35</td>
<td>44</td>
<td>51</td>
<td>44</td>
<td>46</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>47</td>
<td>52</td>
<td>52</td>
<td>48</td>
<td>43</td>
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<td></td>
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<td>56</td>
<td>58</td>
<td>54</td>
<td>57</td>
<td>54</td>
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<tr>
<td>Performance (%)</td>
<td>35</td>
<td>48</td>
<td>57</td>
<td>57</td>
<td>58</td>
<td>63</td>
</tr>
<tr>
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<td></td>
<td>65</td>
<td>54</td>
<td>59</td>
<td>53</td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td>TO (1-5)</td>
<td>35</td>
<td>2.2</td>
<td>2.3</td>
<td>2.2</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>2.4</td>
<td>2.4</td>
<td>2.3</td>
<td>2.4</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>2.5</td>
<td>2.1</td>
<td>2.3</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>2.3</td>
<td>2.3</td>
<td>2.1</td>
<td>2.2</td>
<td>2.4</td>
</tr>
<tr>
<td>IA (1-5)</td>
<td>35</td>
<td>2.0</td>
<td>2.1</td>
<td>1.8</td>
<td>1.9</td>
<td>1.9</td>
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<td>1.9</td>
<td>2.0</td>
<td>2.1</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>1.9</td>
<td>2.2</td>
<td>1.9</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>2.0</td>
<td>2.0</td>
<td>1.9</td>
<td>2.0</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Table 1. Ratings of annoyance, and the index TO and IA for the twenty sound exposures, five sources and four sound levels.

Annoyance

The statistical analysis shows that there is an effect of sound level exposure on rated annoyance \([F(2.8)=139.0, p<.05]\). The significant correlation between sound level and means of rated annoyance \((r=.48)\) is shown in figure 2.

The statistical analysis shows that there is an effect of source of sound exposure on rated annoyance \([F(3.7)=17.6, p=.00]\). The mean of rated annoyance is significantly higher for irrelevant speech than for ventilation noise \(M_{speech}=49.8, M_{ventilation}=41.1, t(47)=4.54, p<.05\), road traffic noise \(M_{speech}=49.8, M_{traffic}=41.9, t(47)=4.31, p<.05\) and classroom noise

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Results

(M_{speech}=49.8, M_{classroom}=39.9, t(47)=5.49, p<.05). The mean of rated annoyance is significantly higher for structure-borne noise than for ventilation noise (M_{structure}=50.9, M_{ventilation}=41.1, t(47)=5.14, p<.05), road traffic noise (M_{structure}=50.9, M_{traffic}=41.9, t(47)=5.46, p<.05) and classroom noise

\[ (M_{structure}=50.9, M_{classroom}=39.9, t(47)=7.31, p<.05). \]

*Figure 2. The relation between sound level and means of rated annoyance.*

There is an interaction between level and source for rated annoyance [F(7.6)=2.50, p=.01]. This is shown in figure 3. For speech and structure-borne sounds, the relation between rated annoyance and level is steeper than for ventilation, road traffic and classroom noise. There is also a ceiling effect for speech and structure-borne sounds for the annoyance/level relation at 55 dB(A).
Results

Figure 3: Rated annoyance for the four sound exposure levels and the five sound sources.

Effort

The statistical analysis shows that there is an effect of sound level exposure on rated effort \([F(2.4)=23.1, p=.00]\). The significant correlation between sound level and means of rated effort \((r=.24)\) is shown in figure 2.

There is an effect of source of sound exposure on rated effort \([F(3.6)=9.18, p=.00]\). The mean of rated effort is significantly higher for irrelevant speech exposure than for ventilation noise exposure \((M_{\text{speech}}=54.1, M_{\text{ventilation}}=48.9, t(47)=3.97, p<.05)\), structure-borne noise exposure \((M_{\text{speech}}=54.1, M_{\text{structure}}=51.7, t(47)=2.11, p<.05)\), traffic noise exposure \((M_{\text{speech}}=54.1, M_{\text{traffic}}=51.3, t(47)=2.43, p<.05)\) and classroom noise exposure \((M_{\text{speech}}=54.1, M_{\text{classroom}}=47.0, t(47)=5.48, p<.05)\).

The mean of rated effort is significantly higher for structure-borne noise exposure than for ventilation noise exposure \((M_{\text{structure}}=51.7, M_{\text{ventilation}}=48.9, t(47)=2.24, p<.05)\), and classroom noise exposure \((M_{\text{structure}}=51.7, M_{\text{classroom}}=47.0, t(47)=4.28, p<.05)\).
Results

Performance
The statistical analysis shows that there is an effect of source of sound exposure on rated performance [$F(3.5)=5.1$, $p=.00$]. The mean of rated performance is significantly lower for irrelevant speech exposure than for traffic noise exposure ($M_{speech}=54.9$, $M_{traffic}=59.1$, $t(47)=-3.65$, $p<.05$) and classroom noise exposure ($M_{speech}=54.9$, $M_{classroom}=58.7$, $t(47)=-3.04$, $p<.05$).

The mean of rated performance is significantly lower for irrelevant speech exposure than for traffic noise exposure ($M_{speech}=54.9$, $M_{traffic}=59.1$, $t(47)=-2.95$, $p<.05$) and classroom noise exposure ($M_{speech}=54.9$, $M_{classroom}=58.7$, $t(47)=-2.92$, $p<.05$).

Task orientation
The statistical analysis shows that there is an effect of source of sound exposure on rated TO [$F(3.4)=3.1$, $p=.02$]. The mean of rated TO is significantly lower for irrelevant speech than for traffic noise exposure ($M_{speech}=2.26$, $M_{traffic}=2.37$, $t(47)=-2.03$, $p<.05$) and classroom noise exposure ($M_{speech}=2.26$, $M_{classroom}=2.41$, $t(47)=-2.19$, $p<.05$).

The mean of rated TO is significantly lower for structure-borne noise exposure than for traffic noise exposure ($M_{structure}=2.23$, $M_{traffic}=2.36$, $t(47)=-2.21$, $p<.05$) and classroom noise exposure ($M_{structure}=2.23$, $M_{classroom}=2.41$, $t(47)=-3.17$, $p<.05$).

Inattentiveness
The statistical analysis shows that there is an effect of source of sound exposure on rated IA [$F(df 3.6)=5.0$, $p=.00$]. The mean of rated IA is significantly higher for irrelevant speech than for ventilation noise ($M_{speech}=2.07$, $M_{ventilation}=1.94$, $t(47)=2.71$, $p<.05$), structure-borne noise ($M_{speech}=2.07$, $M_{structure}=1.91$, $t(47)=3.42$, $p<.05$), road traffic noise ($M_{speech}=2.07$, $M_{traffic}=1.10$, $t(47)=3.59$, $p<.05$), and classroom noise ($M_{speech}=2.07$, $M_{classroom}=1.86$, $t(47)=4.28$, $p<.05$).

Outliers
An analysis of sequence indicated that for one of the sequences the mean rated annoyance is higher than for other sequences [$F(3)=2.97$, $p<.05$]. When the sequence with a higher mean for rated annoyance is removed the effect of source remains. There is an effect of sound level exposure on rated annoyance
Results

\[ F(2.6) = 114.4, p < .05 \] as well as an effect of source of sound exposure on rated annoyance \[ F(3.5) = 13.2, p < .00 \].

An analysis of place indicated that for one of the positions the mean rated annoyance is higher than for other positions \[ F(11, 948) = 5.4, p = .00 \]. When removing the place with a higher mean for rated annoyance the effect of source remains. There is an effect of sound level exposure on rated annoyance \[ F(2.8) = 122.9, p < .05 \] as well as an effect of source of sound exposure on rated annoyance \[ F(3.6) = 16.8, p < .05 \].
DISCUSSION

Noise exposure in the classroom

The results from the field studies (papers I and III) point to speech and structure-borne sound as the most annoying sound sources to the pupils. The laboratory study (paper V) points out that speech and structure-borne sound are more annoying than other sources when the sound stimuli are presented separately. This indicates that the higher annoyance for this source may depend on factors within the source rather than the fact that speech in the classroom is the dominant source.

In the literature, speech appears to be more disturbing than other sources, especially in connection with more difficult verbal tasks (Kjellberg and Sköldström 1991; Jones and Morris 1992; Tremblay et al. 2000; Landström et al. 2002).

The literature shows that annoyance as well as negative effects on performance will increase with variability of the exposure (Kuwano et al. 1980; Holmberg 1997), which is typical of the character of structure-borne sounds such as footsteps, scrapings from chairs and tables and slamming doors as well as for speech.

The sound levels in empty classrooms were mainly due to ambient noise from ventilation, other classrooms and corridors. Results do not clearly support the idea that a lowered background sound level would improve the sound environment by generating a lower activity noise level, although data pointed in that direction.

Studies conducted in other countries identify surrounding road, rail, and air traffic as critical sound sources in the school environment (Hygge 1993). For classrooms studied within the present thesis these types of sound sources were negligible.
The background sound level exposure levels in the classrooms were distributed within the interval of 33 - 42 dB(A)eq. In eight of 24 classrooms the background sound level exceeded the recommendations for work environments where steady concentration and undisturbed communication are essential (Swedish National Board of Occupational Safety and Health 1992). The activity sound level ranged between 47 and 69 dB(A)eq. This is in accordance with earlier studies (Weinstein and Weinstein 1979, Bess et al. 1984, Markides 1986, Pekkarinen and Viljanen 1991, Crandell and Smaldino 1994, Hodgson et al. 1999). These levels must be considered high for a work environment such as the school which has to allow steady concentration and communication in order to facilitate learning.

Despite these high equivalent levels during class (Max 68 dB(A)Leq) the risk of hearing damage during class (music, woodwork and gymnastics excluded) is low. Measures against annoying noise would obviously reduce the risk of hearing damage even more.

According to van Heusden et al. (1979), vocal effort increases as background noise rises over 40 dB(A). As the level rises, the speaker tries to compensate with a raised voice and this causes others to raise their voices. According to Berg et al. (1996) the noise level in the classroom is higher than the conversational voice level of many teachers, making it difficult for the pupils to hear the teacher. In 14 of 24 classrooms measured in paper IV, the level exceeded 55 dB(A)eq for 50 % of the time and in 4 classrooms for 90 % of the time. Arlinger (1999) claims that a noise level of 55 dB(A) generates acceptable speech intelligibility for a person with normal hearing in the age interval 15-55, standing within one metre in front of the speaker and where the speech signal is in the listener’s and speaker’s native language. Airey et al. (1998) assert that children’s listening skills are not yet fully developed, approximately ten percent of the Swedish people have a hearing impairment and ten percent have a native language other than Swedish (Arlinger 1999). It is reasonable to assume that a noise level of 55 dB(A) in a classroom of up to 30 children is not acceptable as regards speech intelligibility. An increasing problem of the working environment in the classroom is voice problems among teachers. A probable cause is the high sound levels in the classrooms that cause the teachers to overstrain their voices.

The indication in the material of an increase in activity sound level of 3 dB when doubling the number of pupils in a class is fairly consistent with the mathematical relation of an increase in sound level of 3 dB for each doubling of sources.
However it is reasonable to assume an S-shaped relationship between class size and activity sound level. In a smaller group sound level is kept low as the individual cooperates with the one group. When the number of individuals increases and the social pattern creates groups within the group a kind of competition between the groups may arise and raise the sound level. Finally the ceiling is reached where the number of individuals no longer affects the sound level.

Pupils listening to music while working were exposed to higher sound levels than other groups but their annoyance rating was lower. This finding gives reason to believe that the ability to mask unwanted components as well as the ability to control the noise is of great importance to the annoyance.
Self-reported mood

Paper II describes the development of a mood-rating instrument to identify effects of noise and other aspects of the classroom environment of importance to the children's scholastic performance. The two unipolar factors that emerged from the factor analysis of the selected words were labelled task orientation and inattentiveness and looked like opposites on a bipolar dimension, but were only moderately correlated and were therefore kept apart. The reliability of the two resulting scales was high and the model explained a large part of the item variance.

The adjective checklist was mainly developed to study effects of noise in the classroom during theory lessons. There is, however, a wider field of applications for this method. It can be used in studies of the effects of other physical environmental factors such as climate and light and as well as work organisation and educational methods.

The high non-response rate for many items showed that it was necessary to adapt the choice of words to the children's vocabulary. None of the 45 words in the first version had caused any problems when used in adult groups.

The correlations between the factor scores and the unweighted means were high, and there is therefore no reason to use the more complicated factor score.

The word list is developed in Swedish for pupils in the upper level of Swedish compulsory schools. The proposed English translations do not, of course, correspond perfectly with the meaning of the Swedish words, but it seems likely that a similar structure would be obtained in a factor analysis of items selected with the same criteria.

The questionnaire is quite easy to administer, takes little time to complete and is therefore well suited to studies in field settings.
Discussion

Annoyance

Even though the sound levels in the classrooms were high and more than 1/3 of the pupils claimed that the existing sound environment in their classroom obstructed their work (paper I) the pupils claimed that they were only moderately annoyed. The ratings of annoyance in paper I correspond to the verbal definition “Somewhat annoying - Rather annoying” and in paper II the annoyance using a five-step response scale corresponds to the verbal definition “Somewhat annoying”. The difficulty in quantifying annoyance makes it hard to say what this represents. A comparison with other groups rating their annoyance caused by noise is hazardous, even though the work and noise exposure is similar. Individual and situational factors other than sound exposure may have considerable effects on the ratings. It is fair to assume that pupils are resigned to the noise situation at their school or compensate for these problems by making a greater effort.

The higher level of rated annoyance for pupils in the 7th grade than for pupils in the 9th grade may reflect an effect of age and maturity and the fact that older pupils have better ability to screen off noise as a source of annoyance and focus on their work. The difficulty in quantifying annoyance makes it hard to say whether nine steps on the 100-step annoyance scale represents a substantial difference.

The results from the field studies (papers I and III), looking at possible relations between sound level and subjective effects, did not support the idea that higher sound levels increase annoyance and inattentiveness, or impair task orientation. In the laboratory setting, a relation between increasing sound level and increase in rated annoyance was displayed. As previously shown there are many factors, acoustical and non-acoustical, affecting the subjective response. Sound level, frequency, variability and duration are a few examples of acoustical factors and attitudes; mood, controllability, hearing impairment are examples of non-auditory factors. A laboratory setting allows increased control and facilitates the study of separate factors.
Low frequency noise in the classroom

One of the field studies shows that the noise in 16 of 22 classrooms investigated is to be regarded as LFN using the method quoted by the Swedish National Board of Health and Welfare (1995). Moreover the statistical analysis did not show that pupils exposed to high LFN levels were more annoyed than pupils exposed to low LFN levels when using the $L_{\text{Ceq}} - L_{\text{Aeq}}$ difference to identify LFN. In the extent of the study, A-weighted and C-weighted levels were calculated for a limited frequency range, 63-20 kHz. The idea was that the classification of high/low LFN exposure should be based on the frequency range where the sound pressure level exceeded the hearing threshold. However, there was still no statistically significant difference in reported annoyance between the high and low LFN exposed groups.

On the basis of earlier research there is a problem in using this method at low levels. High levels at low frequencies may contribute to a high C-weighted level, yet one below the hearing threshold level. If so, the method of identifying LFN may overestimate energy in the lower part of the spectra. Accordingly, Persson Waye (1999) suggests that this method should only be used when the level is above 30 dB(A). There are reasons to believe that a recommended minimum level for the use of this method should be even higher than 30 dB(A). The dominant source of the background sound in these classrooms is ventilation and, therefore, LFN. Yet it is not correct to assume that ventilation noise is to be categorized as LFN at all times. Swedish National Board of Health and Welfare (1995) also points out the necessity of moving on to the use of other methods as 1/3-octave band analyses to confirm an LFN exposure.

The results in this study do not contradict the proposed method of defining the LFN component, nor the view that this definition is a relevant method of assessing the risk of LFN annoyance. Earlier research raises the question whether the frequency weighting with an A-filter is a correct method when assessing the annoyance response to noise especially when containing strong LFN components.
CONCLUSION

The overall purpose of this thesis has been to increase the knowledge on noise exposure in classrooms and the subjective response among pupils. Further to disclose factors of special importance assessing negative noise effects in the classroom.

The background sound levels in the classrooms were mainly due to ambient noise from ventilation. The background sound level in the classrooms were distributed within the interval of 33 - 42 dB(A)eq, this is in accordance to recommendations for this type of work environments. The background sound in two third of the classrooms investigated was considered as low frequency noise (LFN). However, pupils exposed to high LFN levels were not more annoyed than pupils exposed to low LFN levels.

The activity sound level during class ranged between 47 and 69 dB(A)eq. These levels that must be considered to be high for a work environment such as the school, with high demands on steady concentration, communication and learning. There is also an obvious risk that the teacher's voice will not be clearly perceived. However, the risk of hearing damage during class must be considered to be low.

The ratings of annoyance corresponds to the verbal definition “Somewhat annoying - Rather annoying”. There was an indication of a higher level of rated annoyance for younger pupils. Older pupils may have better ability to screen of noise as a sources of annoyance and focus on their work.

The laboratory setting shows a relation between increasing sound level and an increase in rated annoyance and rated effort.

The results points to speech and structure-borne sounds to be the most critical sound sources that affects pupils' ratings of annoyance, effort, performance, task orientation and inattentiveness.
The classroom is the workplace for one fifth of the Swedish population. Every citizen has passed through the school system - a place for education, cognitive, psychological and social development. What we learn and experience in school, is of great importance for our adult roles. "Classroom noise - exposure and subjective response among pupils" is one part of a compelling body of research evidence to show the negative effects of noise on well-being, behaviour and subjective response. Set against current concern about the standards of academic achievement we cannot ignore the importance of the sound environment to meet educational targets.
ACKNOWLEDGEMENT

Är ni kvar?
Jag vill bara passa på att tacka alla som på olika sätt bidragit till det här arbetet med hjälp, uppmuntran och vänskap.

Mina handledare:
Ulf Landström som "satte projektet i sjön", Kjell Holmberg som gått med mig och Lage Burströmm som alltid får en att se möjligheterna.
Anders Kjellberg för att du kan allt och alltid, helhjärtat, ställer upp med hjälp och stöd.
"Vi måste klargöra vilka oklarheter som måste klargöras."
Sonya Hörnqwist-Bylund - min alldeles egna Hildegard.
"Med regelbundna måltider, positiva tankar och nässköljningar kan man komma långt."
Kåre Eriksson för att du lärt mig att man inte blir en häst bara för att man går in i ett stall.
"Det var bättre förr. Ju för desto bättre."
Jonny Hedendahl, rumsgrenna, för att du fått en pojkvasker att förstå att man måste sätta in saker och ting i ett större sammanhang.
"This town needs an enema."
Anna-Sara, Bojjan, Bollis, Fredde, Hönken, Jenny, Jessica, Johan, Jonna, Klas, Neil, Ninni, Nisse, Matte, Peter Z, Familjen Sunesson, Xiao Ru, Åsa:
"Sometimes the one who is clumsy, different or even a little strange just might be the friend you are looking for."
Kollegor vid ALI Norr och Institutionen för Folkhälsa och Klinisk Medicin.
"I don't know half of you half as well as I should like, and I like less than half of you half as well as you deserve."
Insatsstyrka alfa i bullernätverket - Silicone Bengtsson, Bad Boy Johansson, Mad Dog Frenne, Babe Boman och Elektra Enmarker för gott samarbete och vänskap som jag hoppas bestå länge. "The Truth is out there."
Jedi Council of the noise network - Mr Pink Kjellberg, Mr White Arlinger, Mrs blonde Persson Waye, Mr blue Johansson, Mr Orange Hygge and Nice Guy Landström.
"We dreamed of creating the world's most powerful Pokemon... ...and we succeeded."
Svala snubben, Storhellquist, Buffy, Limpan och Mago för att ni på grund av ert svaga intellekt inte haft förmågan att lägga er i mitt arbete.
"Fun is our business."
Lars och Erik - bröder i allt - för att träda som växer i stormen får kraftiga rötter.
"Roseanne Barr naked. Gone!"
Mamma Margareta - för kärlek och säkert spel framför egen kasse.
Pappa Mats - Tack för allt.
Erika - Mitt norr, mitt söder, mitt öst och mitt väst.

För övrigt anser jag att ingen kan äta femtio ägg...

ta ta
P.
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References


*No children or teachers were harmed or mistreated in the making of this Thesis.*
Editor: The Dean of the Faculty of Medicine

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