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Low frequency noise enhances cortisol among noise sensitive subjects during work performance

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Abstract

Salivary free cortisol concentration, rated stress and annoyance were determined in 32 subjects before, during and after carrying out a battery of performance tasks for 2 hours during exposure to ventilation noise, with dominant low frequencies (low frequency noise) or a flat frequency spectrum (reference noise). Both noises had a level of 40 dBA. All subjects were studied on two occasions and were exposed to both noises in strict rotation. Subjects were categorised as high- or low-sensitive to noise in general and low frequency noise in particular on the basis of questionnaires. Cortisol concentrations during the task were not significantly modulated by the noises or related to noise sensitivity alone. The normal circadian decline in cortisol concentration was however significantly attenuated in subjects high-sensitive to noise in general, when they were exposed to the low frequency noise. This noise was rated as more annoying and more disruptive to working capacity than the reference noise. The study showed physiological evidence of increased stress related to noise sensitivity and noise exposure during work. This is the first study to demonstrate an effect of moderate levels of noise on neuroendocrine activity. The impact of long-term exposure to moderate noise levels, and particularly low frequency noise, in the workplace deserves further investigation.

Keywords: Cortisol; Stress; Low frequency noise; Work performance

Introduction

There is a growing body of data to show that low frequency noise has effect characteristics that are different from other environmental noises at comparable levels. The most characteristic symptoms are unusual tiredness, concentration difficulties and a feeling of pressure on

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the head and over the eardrums [1,2]. Exposure to low frequency noise e.g. from ventilation or air-conditioning units has been found to cause general annoyance [3,4] and to impair response time in performance tasks [4].

Many modern working conditions involve a high element of unpredictability, selective attention and processing high loads of information. Employees may be exposed to low frequency noise at the same time when they are expected to carry out tasks with a high information load over which they have little control and which are demanding in terms of selective attention requirements. It is not known how such work demands are affected by the extra load of low frequency noise, but it is possible that even a moderate low frequency noise load can put an extra strain on the individual, enhancing stress responding and leading to detrimental physical and psychological effects.

A multitude of research has been done on the effects of noise on performance, but the results give a rather inconsistent picture [5,6]. A large range of individual differences in noise sensitivity in general, and possibly for low frequency noise in particular, may be one reason for this variation. Subjects highly sensitive to noise in general, as measured by Weinstein's sensitivity scale [7], were found to have the lowest performance accuracy under conditions of exposure to traffic noise [8,9] as well as stronger subjective responses to noise [8]. It has also previously been found that annoyance while performing tasks under noisy condition was higher for subjects sensitive to noise [8], and that subjects disturbed by low frequency noise in their homes were not necessarily sensitive to noise in general, as measured by general noise sensitivity scales, but sensitive to low frequency noise in particular [1]. It is thus important to classify subjects not only in terms of sensitivity to noise in general but also with respect to low frequency noise.

Psychological stress and negative affect are associated with increased secretory activity in the hypothalamic-pituitary-adrenal (HPA) neuroendocrine system. The main secretory product of this neuroendocrine cascade is the glucocorticoid hormone cortisol. Cortisol regulates carbohydrate and lipid metabolism, modulates the immune system and has important influences on mood and cognitive processing [10]. Many of its functions are associated with a marked circadian cycle that is regulated by the hypothalamic suprachiasmatic nucleus [11,12]. The diurnal component of this cycle is characterised by increased activity following awakening in the morning and a declining pattern over the remainder of the day. Inputs from different situations superimpose upon this cycle. Dysregulation of this system and altered circulatory levels of cortisol have been implicated in numerous disease pathologies, both somatic and psychological [13]. It has been shown that the diurnal cortisol profile is elevated in normal individuals during everyday experiences in relation to minor stressors and negative mood [14]. Increased cortisol in relation to a brief psychological stress challenge task has furthermore been shown to interfere with declarative memory [15].

Cortisol levels can be measured in serum, urine and saliva. Cortisol levels in saliva very accurately reflect free, physiologically active, cortisol in the circulation [17,18]. The salivary free cortisol response has been studied under laboratory conditions in relation to a psychosocial stress challenge test and to pharmacological stimulation [see e.g. 16,19]. In addition, studies have been done on ambulatory subjects during their normal daily activities with repeated diurnal sampling to determine influences of minor life events (stressors) and mood on cortisol levels. Such studies have demonstrated an association between negative affect and cortisol elevation in normal individuals during their normal daily routines [14,20]. Differences in the circadian cycle of cortisol have also been associated with a variety of different effects including susceptibility to upper respiratory illness [21].

Several studies have been done in the work place related to real life professional experience. Zeier *et al.* [22] reported a relationship between elevated salivary cortisol concentrations and perceived stress by the work experience, in air traffic controllers during radar work sessions. Similarly, Kugler *et al.* [23] reported marked elevations of salivary cortisol in football coaches as they watched their teams play; elevated cortisol was associated with feelings of excitement and tension during the match.

Some investigations have evaluated the effect of noise on cortisol. High levels of chronic noise exposure (85 to 95 dB L_{Aeq}) were associated with elevated cortisol concentrations (measured in urine three times a day for one week) [24]. When the subjects were equipped with earmuffs, the cortisol concentrations were significantly lower at the end of the work shift as compared to the normal work situation without the earmuffs.

Less is known about elevations in cortisol levels during exposure to moderate levels of noise, and nothing is known about effects of low frequency noise. In view of the influence of cortisol on both cognition [15,25] and mood [26], it is important to study the possible impact of low frequency noise on cortisol during work-task performance and its relation to noise sensitivity.

Aim

The aim of this study was to investigate whether exposure to moderate levels of low frequency noise during mentally demanding work would lead to subjective stress and annoyance and result in increased secretion of cortisol. A further objective was to analyse the influence of noise sensitivity on the cortisol response.

Material and methods

Experimental design

In the study, each subject took part in two test sessions, on separate days and always in the afternoon. The total exposure time was on average 2 hours and 10 minutes with a variation of ±9 min (see Figure 1). The variation was due to the difference in the individuals' performance time carrying out task IV during phase B. During the afternoon, cortisol levels normally follow a gradual circadian declining pattern. Of the 64 sessions, 37 started at 12.30, and 27 started at 15.00. The proportion of subjects starting at 12.30 and 15.00 for the two noise conditions was similar, 18/14 for the low frequency noise condition and 20/12 for the reference noise condition.

The experiment was performed on individual subjects in a $24m^2$ semi-reverberant room, furnished as an office with a desk, computer and bookshelf. The test session consisted of two phases, phase A and B. In each phase, the subject worked with the four tasks. During both test sessions, the subject was continuously exposed to either the low frequency noise or the reference noise. Half of the subjects started with the reference noise and the other half with the low frequency noise.

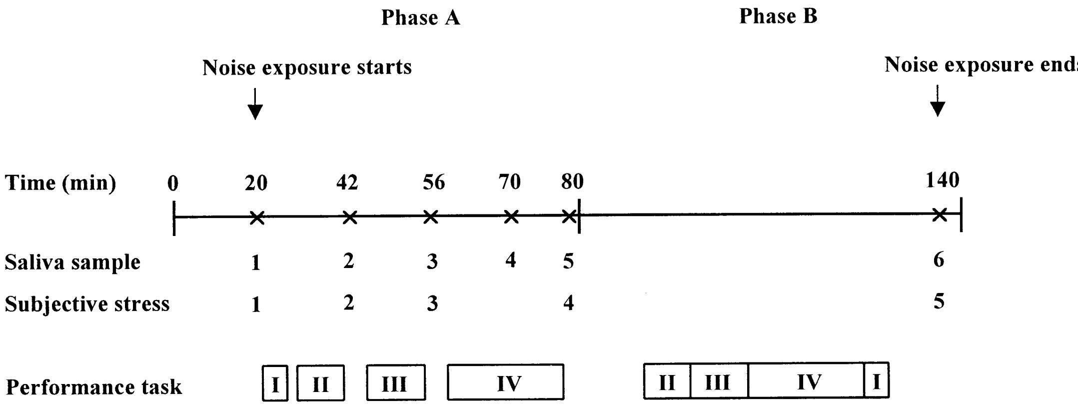

Fig. 1. Schedule for saliva sampling, subjective stress and performance tasks during the two phases in the test session.

Noise exposure

Two noises were used in the study; a reference noise and a low frequency noise (Figure 2). The reference noise was recorded from a ventilation installation and had a flat frequency spectrum. For the low frequency noise, sound pressure levels in the frequency region of 31.5 to 125 Hz were added to the ventilation noise, using a digitalised sound processor system

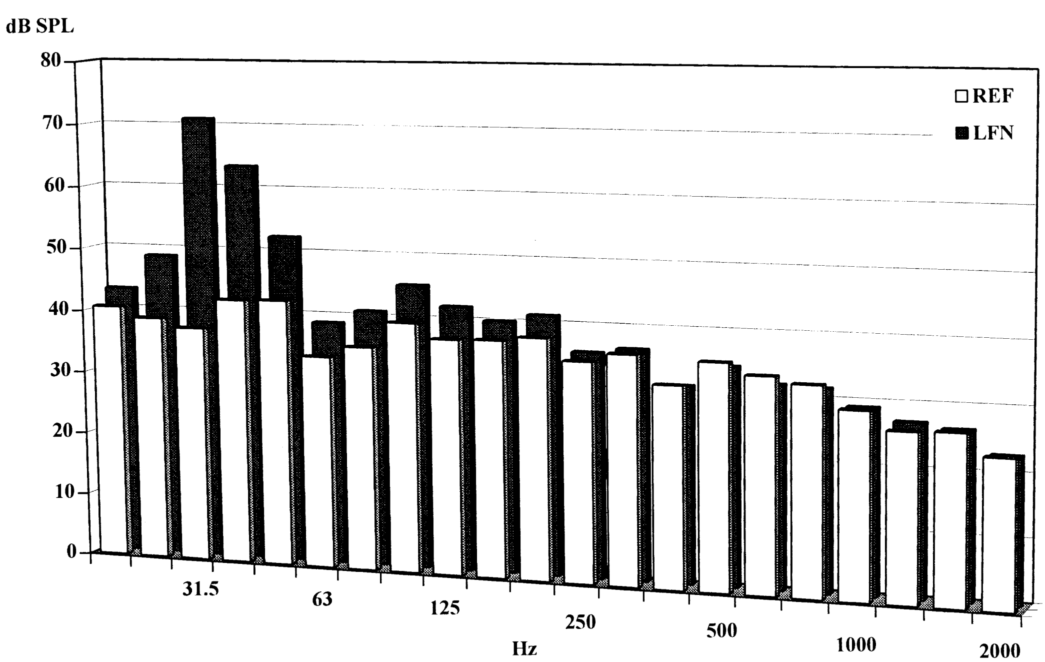

Fig. 2. Third octave band sound pressure levels of the reference noise and the low frequency noise (dark coloured bars), measured at the position of the subject's head.

[Aladdin interactive workbench, Nyvalla DSP Stockholm, Sweden]. Furthermore, the third octave band centred at 31.5 Hz was amplitude-modulated with an amplitude modulation frequency of 2 Hz. Both noises had a level of 40 dBA.

Subjects

Subjects were recruited by advertising and were given financial compensation for their participation. Each potential subject underwent a hearing test [SA 201 II Audiometer, Entomed, Malmö, Sweden] and only persons with normal hearing, <20 dB HL, were admitted to the study. The study was approved by the local ethics committee. Nineteen female and 13 male subjects with an average age of 23.3 (Sd=2.58) years took part.

Subjective sensitivity to noise

To assess noise sensitivity, two questionnaires were answered after the last test session.

On the basis of the subjects' scores on two of the questions in the questionnaires, subjects were categorised as highly sensitive (high-sensitive) or less sensitive (low-sensitive) to low frequency noise. The first question "are you sensitive to low frequency noise" had five response alternatives ranging from "not at all" to "extremely sensitive". The second item "I am sensitive to rumbling noise from ventilation systems", had six response alternatives ranging from "do not agree at all" to "agree completely". The subjects were also categorised as highly sensitive (high-sensitive) or less sensitive (low-sensitive) to noise in general, using the question "are you sensitive to noise in general" (with five response alternatives ranging from "not at all" to "extremely sensitive") and using the total number of points scored in Weinstein's noise sensitivity evaluation questionnaire [7]. The questionnaire had a total of 120 points, and was scored such that the higher the point scores the higher sensitivity to noise. The subjects' answers ranged between 40 and 114 points, with an average of 70.8.

The categories of sensitivity were elicited through a principal component analysis with direct oblimin rotation of the four noise sensitivity questions. Two correlating factors, which explained 85% of the variance, were extracted together. In the first factor, the questions on sensitivity to low frequency noise had a load of 0.9 and the questions on sensitivity to noise in general had a load below 0.5. The other factor showed the opposite load pattern. The correlation between the two factors was 0.46. Factor scores were calculated for both the two factors and the four categories (high-sensitive/low-sensitive to low frequency noise and to noise in general) were formed against the median of the points for the two factors.

In the group, 15 females and three males were found to be high-sensitive to low frequency noise, and four females and ten males were low-sensitive to low frequency noise. Eleven females and five males were categorised as high-sensitive to noise in general, and eight females and eight males were low-sensitive to noise in general. The two categorisations were virtually independent (chi2=0.508, p=0.473).

Saliva sampling and cortisol determination

To assess task-induced stress and to evaluate the difference in stress between the two noise conditions, six saliva samples were collected at different times during the experiment. The saliva samples were taken using the salivette saliva sampling device [Sarstedt Ltd, Leicester

UK]. The subject was asked to chew on a sterile dental swab for exactly three minutes. Samples were kept at −70°C, until analysis. To allow for a proper baseline level, the subjects were instructed to take nothing by mouth other than water for at least 45 min prior to, and during, the test session and to avoid rushing to the laboratory. In the laboratory, the subject sat to relax for 20 minutes before the first sample (1) was taken [see 16]. Thereafter, the noise exposure and test session started.

Four saliva samples (2, 3, 4 and 5) were taken during the first phase of the test session. A final sample (6) was taken at the end of the second phase (after 140 min). A total of six saliva samples were taken, of which the first served as a baseline value (mean base). Exact details of the saliva sampling times are given in Figure 1.

Saliva was recovered from the cotton dental swab by centrifugation at 1,000g. and cortisol was determined by ELISA, specifically designed for the assay of cortisol in saliva (Salimetrics) inter and intra assay % CV= <10%. [27].

Performance tasks

In the experiment, four performance tasks were used. The tasks were chosen in order to involve different levels of mental processing. A high workload was generated by instructing the subjects to work as rapidly and correctly as possible. All performance tasks were performed twice in each test session, once in phase A and once in phase B.

Task I was a *simple reaction-time task.* The subject was told to press a button as quickly as possible when a red square appeared on a black screen.

Task II was a *short-term memory task*, which measured reaction time and short-term memory. A set of numbers, e.g. 1 2 5 4, was presented on the computer screen. This set was followed by one number, e.g. 7. The subject was to respond, by yes or no, to whether the number was also present among the set of numbers shown earlier.

Task II was performed together with a secondary task, the *bulb-task*, previously used by Persson Waye *et al.* [4]. The task consisted of four differently coloured light bulbs, placed at four different positions on an arch in the periphery of the subject's visual field. Each of the four bulbs was illuminated at random intervals and in a random sequence. The subject's task was to respond only when a yellow bulb was illuminated, after which the subject was instructed to, as quickly as possible, push a response button that matched the colour (red, green or blue) of the coloured bulb that was lighted *prior* to the yellow light bulb. The set-up used for task II with a primary and secondary object was designed to engage the subject's full attention and necessitates a high degree of concentration.

Task III was a *proof-reading task* with contextual and grammatical errors, previously used by Landström *et al.* [28]. The subjects read a text printed on paper for exactly ten minutes and were instructed to mark errors in the text.

Finally, task IV was a computerised *verbal grammatical reasoning task*, translated into Swedish from the original version [29]. The task is based on grammatical transformation of sentences that have various passive, active, negative and positive structures. The subject was instructed to respond to whether a sentence is false or true in relation to a letter combination following the sentence. The set-up used for task IV was designed to require a high degree of mental capacity.

Tasks I, II and IV involved working with a computer and task III with pen and paper. Tasks I and IV were part of a computerised Swedish performance evaluation system [30].

Questionnaires

Following tasks II, III and IV, the subject rated the degree of effort used for each task on a five graded scale ranging from “none at all” to “extremely”.

Following saliva samples 1, 2, 3, 4 and 6, the subject answered a questionnaire evaluating stress and energy by responding to 12 adjectives describing stress and energy [31]. The rating for each adjective was given by one of six response alternatives ranging from “not at all” to “very, very much”.

When the test session was completed, the subject was asked to judge whether his/her capacity to work had been improved or been impaired due to noise, temperature or light during the tasks. The subject chose between seven response alternatives ranging from one to seven: “major improvement”, “rather much improvement”, “some improvement”, “neither improvement or impairment”, “some impairment”, “rather much impairment” and “major impairment”. The questionnaire also contained questions on the presence of symptoms experienced during or after the test session with five response alternatives ranging from “not at all” to “extremely”, and questions on annoyance caused by the noise with five response alternatives ranging from one to five: “not at all annoyed”, “a little annoyed”, “rather annoyed”, “very annoyed” and “extremely annoyed”.

Before and after the test session a questionnaire evaluating mood [32] was completed. The questionnaire consisted of 71 adjectives describing feelings that formed the following six mood dimensions: social orientation, pleasantness, activation, extraversion, calmness and control. The subject could choose between four response alternatives: “I agree completely”, “I somewhat agree “, “I do not agree” and “I do not agree at all”.

Statistical treatment

Analysis was performed on cortisol concentrations expressed as square roots of raw data to counteract initially skewed distributions. Correction did not change any significance decision and original degrees of freedom are reported along with p-values.

Analysis of cortisol secretion during the test sessions was made in relation to the initial sample (sample 1), expressing the change as percentage above or below the population mean. The same procedure was also used for rated stress.

Analysis was carried out by a 6 (cortisol) $\times$ 2 (noise conditions) $\times$ 2 (sensitivity groups) ANOVA. Two factors were within-subjects: cortisol and noise condition (low frequency and reference). Sensitivity to low frequency noise and to noise in general (high and low) was a between-subjects factor. Within-subjects effects were routinely checked for continued significance following a Greenhouse-Geisser correction for sphericity when appropriate.

Correlations between subjective and objective measures were done using Pearson’s correlation analysis. In the analysis of cortisol to rated stress, the rating of stress was related to the corresponding saliva sample. In the analysis of the relationship between cortisol concentration, annoyance and impaired working capacity caused by the noise condition, cortisol scores were computed expressing the test session as a mean value of samples 2–6. This was done as rated annoyance and impairment were assumed to reflect the experience during the whole test session.

In order to analyse the relationship of cortisol concentration and rated stress with performance, ratios of performance for task II and task IV in phase B were divided with the results in phase A. The performance ratios were compared to ratios of cortisol taken at the end of phase B divided with cortisol taken directly after respective task. The same procedure was also carried out for rated stress. This analysis was done in order to evaluate a temporal association.

The statistical analyses were done using SPSS [SPSS base 10.0 for Windows]. All tests were two-tailed, and a p-value of <0.05 was considered statistically significant, while a p-value up to 0.10 is reported as a tendency.

Results

Cortisol

A first analysis was done to see whether the cortisol levels during the test session differed by noise condition and/or subjective sensitivity to noise. Means for all subjects showed that cortisol was significantly decreased at the last sampling point compared to the mean base sample during both noise conditions ($F(1,29) = 26.598$, $p<0.001$). This was in accordance with expectation based on known circadian effects. No significant difference for cortisol level was found between subjects starting the test session at 12.30 as compared to those started at 15.00 ($F(1,29) = 0.296$ $p=0.59$). There was no significant interactive effect of noise in relation to cortisol over time. However, a significant 3-way interaction between noise condition, time period and sensitivity to noise in general was obtained for this key comparison ($F(1,28) = 4.681$, $p<0.05$). Figure 3 shows the average values of cortisol during the low frequency noise condition for subjects high-sensitive and low-sensitive to noise in general.

In the low frequency noise condition, as can be seen in Figure 3, subjects high-sensitive to noise in general maintained higher cortisol levels, relative to mean base values, during the test session as compared to low-sensitive subjects.

In the reference noise condition, Figure 4, an opposite but less pronounced pattern was found.

Thus, higher relative cortisol values during the test session were associated with the combination of being high-sensitive to noise in general and being exposed to low frequency noise.

When the same analysis was done for subjects categorised into sensitivity to low frequency noise, a tendency was seen toward the same 3-way interaction between noise condition, time period and sensitivity ($F(1,28) = 3.736$, $p=0.063$).

No significant differences in cortisol levels were found for gender or order of noise ($F=2.072$, $p=0.157$; $F=0.357$, $p=0.555$).

Rated stress

The average values related to mean base of rated stress responses are shown in Table 1.

A significant interaction between noise and time was found for rated stress ($F(1,28) = 6.081$, $p<0.05$). The value for rated stress was highest during the times for the second and fourth questionnaires ($F(1,28) = 15.066$, $p<0.001$), which was in accordance with the rated effort. At these times the subjects had worked with task II in combination with the bulb-task and task IV. In general, subjects reported a higher value on stress during exposure to refer-

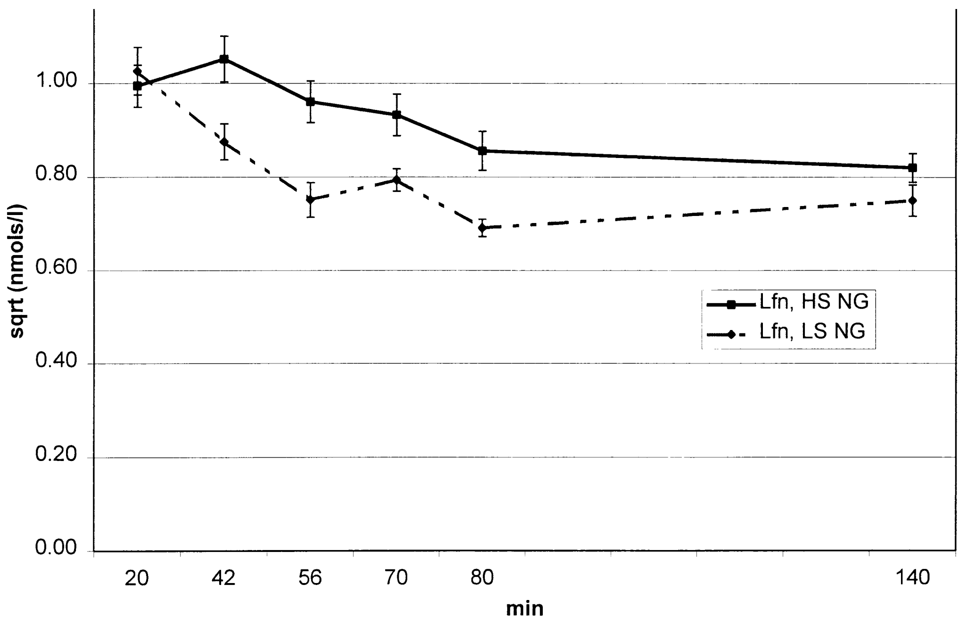

Fig. 3. Average values and standard errors (re. mean base) of cortisol during the test session for subjects high-sensitive (HS) and low-sensitive (LS) to noise in general, during the low frequency noise condition.

ence noise compared to low frequency noise ($F(1,28) = 11.313$, $p < 0.005$). Regardless of noise condition, subjects high-sensitive to low frequency noise generally rated a higher value on stress compared to low-sensitive subjects ($F(1,27) = 5.810$, $p < 0.05$). No significant difference was found when the subjects were sub-divided into sensitivity to noise in general.

Task performance

A main effect of noise condition over time was found for the proof-reading task for total marks per line ($F(1,31)=7.018$, $p<0.05$). Subjects made fewer total marks per line in phase B during exposure to low frequency noise. A two-way interaction between noise and phase was found for the verbal grammatical reasoning task ($F(1,31)=5.750$, $p<0.05$). A longer response time was found in phase B during exposure to low frequency noise. For both tasks, subjects high-sensitive to low frequency noise and high-sensitive to noise in general showed poorer task performance.

There were no significant main effects of noise condition in the simple reaction-time task, the short-term memory task or the bulb-task ($F(1,29)=1.952$, $p=0.173$, $F(1,31)= 0.561$, $p=0.46$ and $F(1,31)=0.304$, $p=0.585$).

Subjective estimations

The low frequency noise was rated on average as more annoying than the reference noise (2.5 versus 2.0; $F(1,31)=9.922$, $p<0.005$). Subjects high-sensitive to low frequency noise were more annoyed by the low frequency noise than by the reference noise, while low-sensitive subjects reported on average the same annoyance after both noises. Low frequency noise was

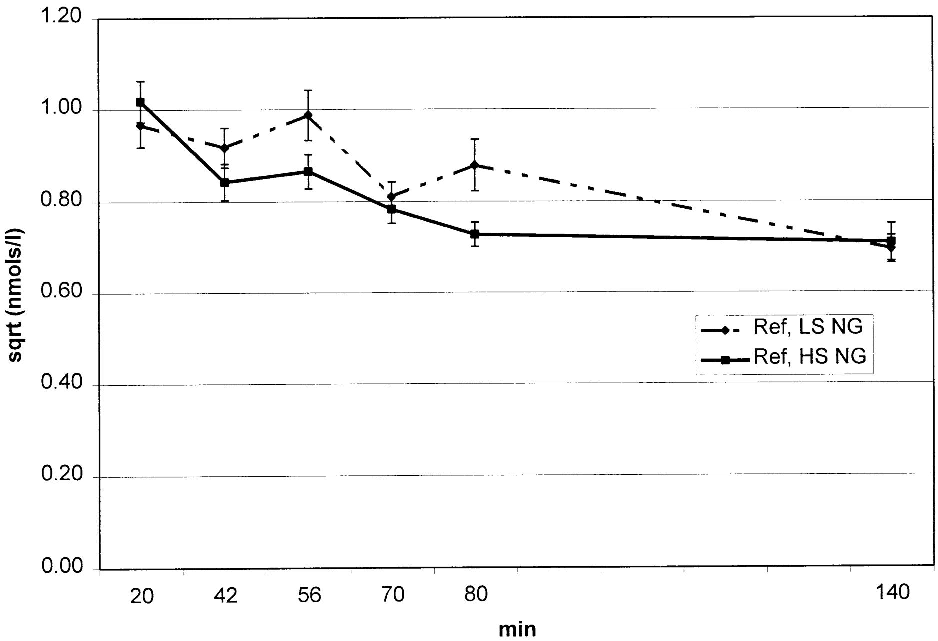

Fig. 4. Average values and standard errors (re. mean base) of cortisol during the test session for subjects high-sensitive (HS) and low-sensitive (LS) to noise in general, during the reference noise condition.

also on average considered to impair working capacity more than the reference noise (5.2 versus 4.8; $F(1,31)=6.808$, $p<0.05$).

The average values of rated effort after the performance tasks were not significantly different between noises and no significant main effect of noise was found for the mood dimensions or for the subjective symptoms. There was however a significant two-way interaction between noise, phase and low frequency noise sensitivity for perception of "being in control"

Table 1
Subjectively rated stress (re. mean base) for all subjects and subjects categorised according to sensitivity to noise in general and to low frequency noise

Questionnaire		1	2	3	4	5
(min)		(20)	(42)	(56)	(70)	(140)
Reference noise	All subjects	**1.1**	**2.1**	**1.7**	**2.4**	**1.9**
	High-sensitive LFN	1.2	2.3	1.9	2.6	1.9
	Low-sensitive LFN	0.9	1.8	1.4	2.1	1.8
	High-sensitive NG	1.1	2.0	1.8	2.5	1.8
	Low-sensitive NG	1.0	2.1	1.6	2.3	1.9
Low frequency noise	All subjects	**1.0**	**1.9**	**1.5**	**1.7**	**1.6**
	High-sensitive LFN	1.1	2.1	1.7	2.1	1.8
	Low-sensitive LFN	1.0	1.8	1.3	1.5	1.3
	High-sensitive NG	1.2	2.0	1.6	2.0	1.6
	Low-sensitive NG	0.8	1.8	1.3	1.7	1.5

($F(1,29)=4.352$, $p<0.05$). The perception of "being in control" among subjects high-sensitive to low frequency noise was lower after as compared to before the exposure to low frequency noise. The opposite results were found for low-sensitive subjects.

Impaired working capacity caused by exposure to low frequency noise was significantly correlated to lack of concentration ($r_{xy}=0.507$, $p<0.005$), nausea ($r_{xy}=0.460$, $p<0.01$), tiredness ($r_{xy}=0.471$, $p<0.01$) and a feeling of pressure on the head ($r_{xy}=0.494$, $p<0.005$). No significant correlation between noise impairment due to reference noise and symptoms was found.

Correlation analysis of cortisol and rated stress in relation to task performance and subjective estimations

Cortisol levels were not clearly related to the ratings of stress. A positive relationship was found only for the second saliva sample for subjects high-sensitive to low frequency noise ($r_{xy} = 0.583$, $n=18$, $p<0.05$) and a negative relationship was found for the first saliva sample for subjects low-sensitive to noise in general ($r_{xy} = -0.549$, $n=16$, $p<0.05$). No significant correlations were found during the reference noise condition.

A tendency toward a relationship between a longer response time in task IV and a higher value on cortisol was found during low frequency noise ($r_{xy} = -0.324$, $n=32$, $p=0.070$). During performance in reference noise a reverse and non-significant relationship was found ($r_{xy} = 0.286$, $n=32$, $p=0.112$). No significant correlations for task IV and rated stress or for task II and cortisol or rated stress were found.

The perception of a lower value of "being in control" after exposure to low frequency noise was significantly correlated to a higher value of rated stress for the whole group ($r_{xy} = -0.582$, $n=28$, $p<0.001$).

Discussion

The study was set out to replicate a normal office work situation. The furnishing of the laboratory, the tasks and the working conditions could well be found in such a workplace. The noises used were representative for noises emitted from air-conditioning or ventilation systems and the level of 40 dBA is within the recommended levels for office work in Sweden [33]. While the design and noise exposures thus have a high ecological validity, the subjects were young and motivated and worked only for a limited period of time. Hence, in order to draw conclusions on effects in a real life situation, field studies among exposed personnel are needed. The major finding in the study was that among subjects categorised as high-sensitive to noise in general, the normal circadian decline in cortisol levels was attenuated when they were exposed to low frequency noise.

Under the hypothesis that increased cortisol levels are indicative of impaired performance due to noise, this finding is in agreement with the results of the performance tasks, as impaired performance was most consistently found among individuals high-sensitive to noise in general as well as among individuals high-sensitive to low frequency noise during the low frequency noise condition. The hypothesis is further supported by the tendency toward a relationship between a longer response time and increased levels of cortisol, during work with the most demanding task (task IV) in the low frequency noise condition.

It has not previously been found that noise sensitivity has been associated with increased salivary cortisol levels. Other personality traits have been found to be of importance, however. In a study among 120 subjects, negative affect was significantly associated with increased salivary cortisol levels evoked by naturally occurring daily stressors [14]. Kirschbaum *et al.* [34] found that the mean cortisol response was related to the concept of one's own competence, extraversion, social resonance and trustfulness, and that high-cortisol respondents viewed themselves as being less attractive than others, having less self-esteem, being more often in a depressed mood and also, reported more symptoms than low-cortisol respondents. In studies of noise effects, both negative affect and noise sensitivity have been found to be of importance for the variability in noise effects, although they are not considered to be equivalent measures [35]. In studies of noise effects, noise sensitivity is the personality trait that has most consistently been found to be of importance for noise annoyance [36,37] as well as for performance [8,9], and was therefore the personality trait chosen for the classification of the test subjects in this study.

The cortisol elevation under exposure to low frequency noise among subjects high-sensitive to noise in general was relatively small. It is well known that cortisol is related to important health parameters including stress and effects on the immune system [10,13]. It might thus *a priori* be hypothesised that changes in cortisol levels, particularly those of a chronic nature, exert a negative influence on health and can be used as an indicator of unsatisfactory working conditions.

The changes in the neuroendocrine system were not clearly reflected in the subjective rating of stress as a positive correlation between cortisol level and stress was only found at one of the measured occasions and only for subjects high-sensitive to low frequency noise. The subjective rating of stress was higher during work in the reference noise as compared to low frequency noise, while the performance was impaired to a higher degree during the low frequency noise condition. The explanation of these results are not clear, but may indicate that the rating of stress was interpreted differently among individuals and depending on the individuals' interpretation of their success. The feeling of being able to work rapidly in the reference condition could thus *per se* result in a high rating of stress, while the feeling of not being able to work as rapidly in the low frequency noise condition may be perceived not only as stressful, but also as a perception of not "being in control". These interpretations may have confounded the rating of stress. These theories should be evaluated in further studies using a more refined stress questionnaire.

The duration of the task series was about 2 hours and all experimental test sessions were performed in the afternoon. We have no data to suggest how cortisol secretory activity may be influenced by exposure to low frequency noise over an entire working day or in relation to day after day work experience. Earlier studies have shown that the cortisol response may habituate for certain external stimuli but not for others [34]. Generally, stress induced by work tasks shows little habituation and particularly demanding tasks, such as two of the tasks used here, probably cause increased stress with time. In a continuation of this work, it would be pertinent to evaluate the habituation effects for the kind of task performance studied here.

Subjects rated the low frequency noise exposure during task performance as more annoying than the reference noise and also considered that it impaired their working capacity. Independent analysis of task performance in an earlier study [4] endorse that the low frequency noise does impair task performance in verbal tasks that demand a rather high degree of cognitive processing.

In summary, the results of the study suggest that exposure to low frequency noise caused alterations in cortisol levels among subjects categorised as high-sensitive to noise in general. No previous studies have been able to show such effects after exposure to low frequency noise and the results are especially interesting in view of the low exposure levels used. It would be of interest to further assess the importance of prolonged exposures and habituation for the effects studied here.

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