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EFFECTS ON PERFORMANCE AND WORK QUALITY DUE TO LOW FREQUENCY VENTILATION NOISE

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A pilot study was carried out to assess method evaluating effects of low frequency noise on performance. Of special interest was to study objective and subjective effects over time. Two ventilation noises were used, one of a predominantly mid frequency character and the other of a predominantly low frequency character. Both had an NC value of 35. For the study, 50 students were recruited and 30 selected on the basis of subjective reports of pressure on the eardrum after exposure to a low frequency noise. Of these, 14 randomly selected subjects aged 21 to 34 took part. The subjects performed three computerized cognitive tests in the mid frequency or the low frequency noise condition alternatively. Tests I and II were performed together with a secondary task.

Questionnaires were used to evaluate subjective symptoms, effects on mood and estimated interference with the test results due to temperature, light and noise. The results showed that the subjective estimations of noise interference with performance were higher for the low frequency noise ($p < 0{\cdot}05$). The exposure to low frequency noise resulted in lower social orientation ($p < 0{\cdot}05$) (more disagreeable, less co-operative, helpful) and a tendency to lower pleasantness ($p = 0{\cdot}07$) (more bothered, less content) as compared to the mid frequency noise exposure. Data from test III may indicate that the response time during the last part of the test was longer in the low frequency noise exposure. The effects seemed to appear over time. The hypothesis that cognitive demands are less well coped with under the low frequency noise condition, needs to be further studied. The results further indicate that the NC curves do not fully assess the negative effects of low frequency noise on work performance.

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1. BACKGROUND

In occupational environments such as control rooms and office-like areas, there is growing concern as to the effects of low frequency noise (20–200 Hz). Low frequency noise may be emitted from ventilation, heating and air-conditioning (HVAC) systems or may occur as a result of the selective attenuation of walls, floor etc. A few previous studies indicate that low frequency noise may reduce performance at levels that can occur in such occupational environments [1, 2]. Some of the symptoms that are related to exposure to low frequency noise such as mental tiredness, lack of concentration and headache related symptoms, could be associated with a reduced performance and work satisfaction.

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2. AIM

A pilot study was carried out to assess methods evaluating effects of low frequency noise on performance. Of special interest was to study objective and subjective effects on performance involving cognitive aspects over time.

3. METHODS

3.1. EXPOSURE NOISES

The exposure noises were two ventilation noises, one of a predominantly mid frequency character (mid frequency noise) and the other was of a predominantly low frequency character (low frequency noise). The mid frequency noise was recorded from a ventilation installation. To obtain the low frequency noise, sound pressure levels in the frequency region of 31·5 to 125 Hz were added to the ventilation noise by a digitalized sound processor system (Aladdin interactive workbench). A tone at 31·5 Hz was amplitude-modulated with an amplitude frequency of 2 Hz. The low frequency noise was perceived as indistinguishable from rumbly ventilation noise. The sound pressure levels of the frequency spectra in octave bands for the two sounds closely followed the NC 35 curve. The dB(A) value was 41 dB(A) for the mid frequency noise and 42 dB(A) for the low frequency noise. The third octave band sound pressure levels of the two noises are shown in Figure 1. Figure 2 shows the octave band sound pressure levels related to the noise criterion of NC 15–NC 45.

3.2. TEST SUBJECTS

For the study, 50 students were recruited by advertising. They were exposed to a low frequency noise, and the 30 who reported a feeling of pressure over the eardrum were included in the study. Of these, 14 randomly selected healthy subjects with an average age of 25 years (21–34) took part.

3.3. TEST CHAMBER

The experiment was performed in a test chamber (24 m^2) furnished as an office environment. The background noise from the normal ventilation was less than 22 dB(A), and the sound pressure levels were below the threshold of normal hearing for the frequency region below 160 Hz [3]. The noise was emitted from four loudspeakers placed in each

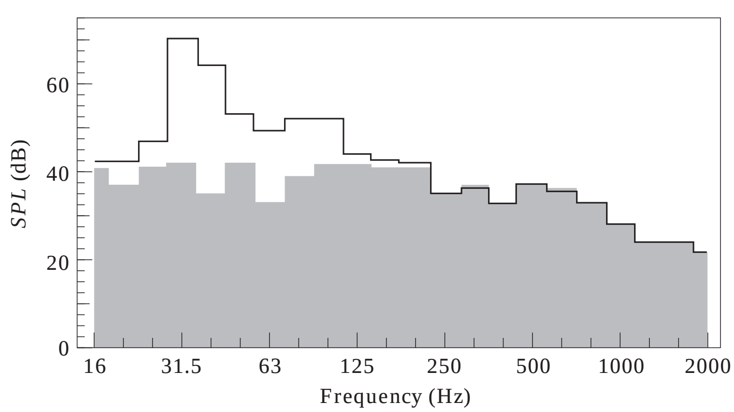

Figure 1. The equivalent third octave band sound pressure levels of the two exposure noises. The low frequency noise is marked with an unbroken line and the shaded area represents the mid frequency noise.

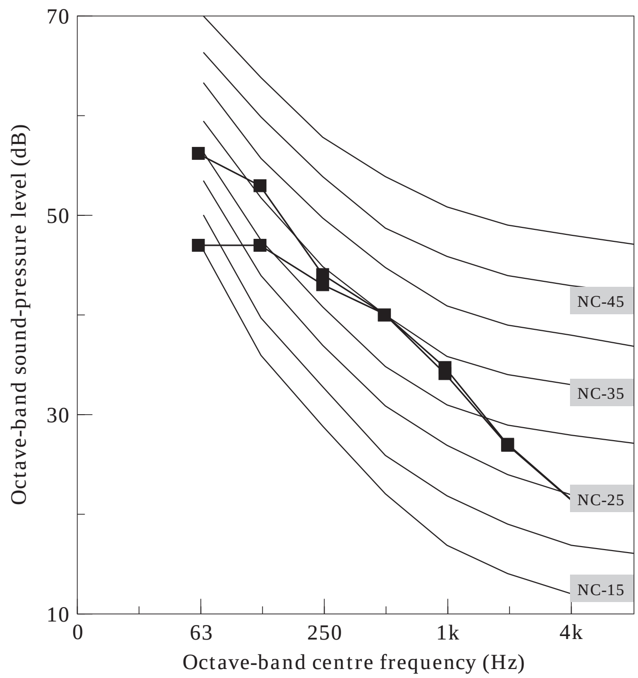

Figure 2. The equivalent octave band sound pressure levels of the two exposure noises in relation to the noise criterion curves of NC 15–NC 45.

corner of the room and hidden behind curtains and thus presenting no obvious visual distraction.

3.4. PERFORMANCE TESTS

The subjects performed three computerized cognitive tests. Test I was a rotation figure test. Two figures were presented on the screen and the object of the test was to identify as quickly as possible whether the left figure was rotated or inverted in relation to the right figure. The response time and correct/false number of answers were recorded. Test II was a short term memory test. On the screen, a set of numbers e.g., 1586, was presented. This was followed by one number, e.g., 5. The subjects was to respond to whether the number (5) was among the set of numbers (1586) presented directly before. The response time and correct/false number of answers were recorded. Test III was a verbal reasoning test developed by Baddeley [4]. It was translated into Swedish and added to the computerized Swedish performance evaluation system (SPES) [5]. The test is based on grammatical transformation of sentences that are varied in passive, active, negative and positive structures. The subject is requested to respond to whether the sentences are false or true in relation to a letter combination following the sentences. For example:

		True	False
A is not followed by B	BA	√	
B precedes A	AB		√

In total, the test included six blocks of 32 different sentences. Response time and correct/false answers were recorded.

Tests I and II were performed together with a secondary task which consisted of a set of four lamps placed in four different positions on an arch in the periphery of the subject's visual field. Each of the four lamps was lit up at random intervals and in random sequence. The subjects were to respond to only one of the four coloured lamps (the yellow lamp) by pushing the button with the colour that corresponded to the lamp that was lit at a random interval before the yellow lamp. The secondary test created an interactive environment which led to a competition of cognitive resources, simulating a basic demand in most working situations.

3.5. DESIGN

The first session was always a learning session performed in background mid frequency ventilation noise (< NC 30). The following two sessions were performed alternatively in the mid frequency noise or the low frequency noise, both at a level of NC 35. The sessions took place in the afternoons of separate days. The total length of the test session was 60 minutes Before and after the test session, the subjects answered a questionnaire evaluating mood [6]. After the session, a questionnaire was answered evaluating subjective symptoms that had earlier been found to be associated with low frequency noise exposure, such as headache, a feeling of pressure on the head, fatigue, irritation, a feeling of pressure on the eardrum, nausea, dizziness and concentration difficulties. Also included were symptoms that were not associated with low frequency noise exposure, such as eye irritation, throat irritation and a sensation of unpleasant taste. Finally, a question was posed on estimated interference with the test results caused by temperature, light and noise and estimated annoyance due to noise.

3.6. STATISTICAL ANALYSIS

The subjective ratings and the difference in mood before and after the exposures were analysed using Student's test two sided, for dependent data. Relationships between subjective and objective data were analyzed using Pearson's correlations coefficient: p-values below 0·05 were considered statistically significant.

4. RESULTS

Figure 3 shows the average value of subjective ratings of interference with performance caused by the different noise exposures. The Figure also includes the response to the mid frequency ventilation noise of < 30 NC which was present during the learning session (N).

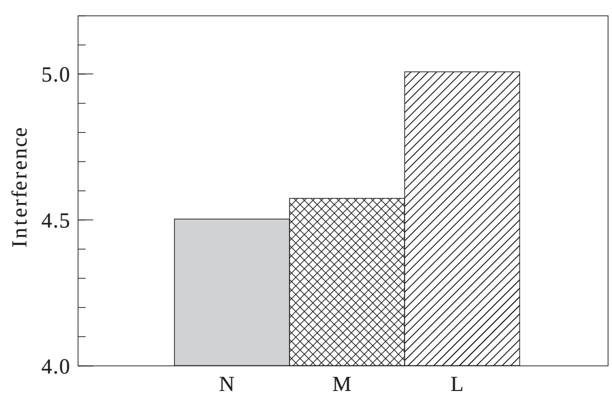

Figure 3. The average value of the estimated interference with performance in relation to the learning session (N), the mid (M) and the low (L) frequency exposure noises.

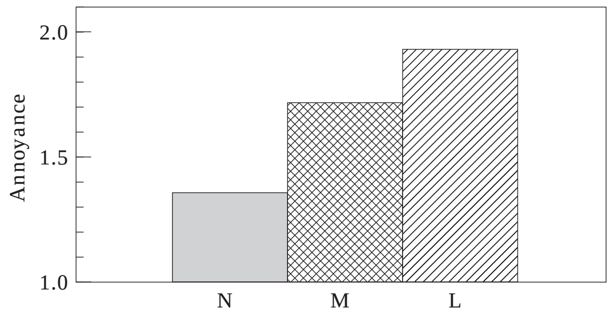

Figure 4. The average value of estimated annoyance for the different noise exposures. Key as Figure 3.

The value of 4 refers to "no interference" and the value of 5 refers to "performance somewhat decreased". It can be seen in Figure 3 that the average estimation of noise interference with performance was higher for the low frequency noise condition ($p < 0{\cdot}05$), as compared to the mid frequency noise condition.

The average value of estimated annoyance is shown in Figure 4. The value of 1 referred to "not at all annoying" and the value 2 referred to "somewhat annoying". It can be seen in Figure 4 that estimated annoyance followed the pattern displayed in Figure 3. However, the difference in annoyance between the low frequency noise and the mid frequency noise was not statistically significant ($p = 0{\cdot}19$).

Reported symptoms were generally low. There was a tendency towards higher reports of a feeling of pressure on the eardrum after the low frequency noise exposure ($p = 0{\cdot}089$), which was in accordance with what was expected owing to the selection criteria of the subjects. It can also be noted that the subjects reported a feeling of pressure on the head rather than headache after the low frequency noise exposure. The difference between the low and mid frequency noises was however not significant ($p = 0{\cdot}18$).

Figures 5 and 6 show the average value of social orientation and pleasantness before and after the exposures for the low frequency noise and the mid frequency noise. A lower social orientation ($p < 0{\cdot}05$) (subjects felt more disagreeable, irritated, ill-tempered, less co-operative, helpful) and a tendency to lower pleasantness ($p = 0{\cdot}07$) (subjects felt more bothered, depressed, less content) were found after the exposure to the low frequency noise as compared to the before and after scores for the mid frequency noise exposure. The average values of the response time for the six different time periods in test III for the two exposure noises are shown in Table 1. It can be observed from Table 1 that the response time showed a tendency towards a decrease for the mid frequency noise, while this is not

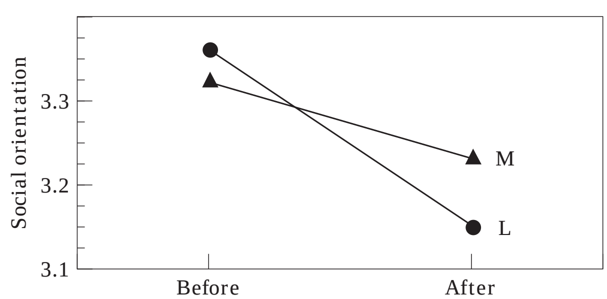

Figure 5. The average value of social orientation before and after the exposure to the low frequency noise (L) and the mid frequency noise (M).

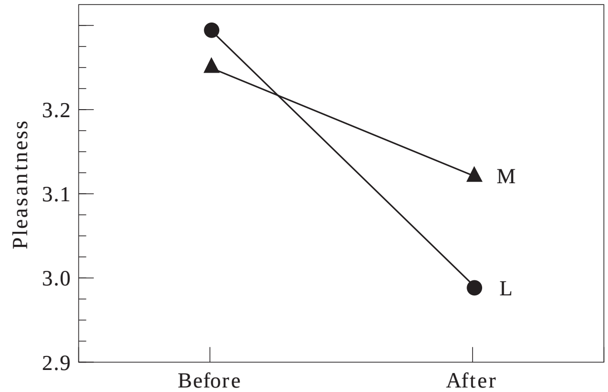

Figure 6. The average value of pleasantness before and after the exposures. Key as Figure 5.

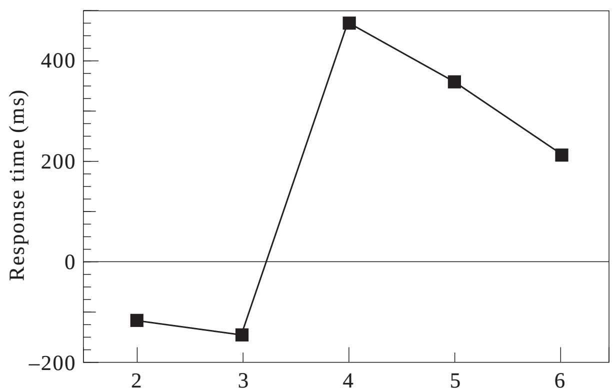

Figure 7. The average value of the individual difference in response times for the two ventilation noises. The x axis shows equal blocks of the verbal test.

seen for the low frequency noise. Also of interest is the standard deviation, which decreased over time for the mid frequency noise and increased over time for the low frequency noise.

Owing to the variance and the small number of subjects, a statistical analysis was not meaningful at this stage. To investigate the tendency seen in Table 1 more closely, an analysis was made of the difference between each individual's response time for the two noises. The average values of these differences are shown in Figure 7. The x-axis in the figure shows blocks of equal numbers of sentences, with the first block excluded. The x-axis

Table 1

The average values of the response time and standard deviation for the six time periods in test III for the mid frequency noise (M) *and the low frequency noise* (L)

Noise time period	M		L	
	Average value (ms)	SD	Average value (ms)	SD
1	3332	2066	2733	700
2	2776	1003	2657	627
3	2633	1033	2477	558
4	2477	863	2953	1009
5	2516	526	2875	1545
6	2543	677	2757	1776

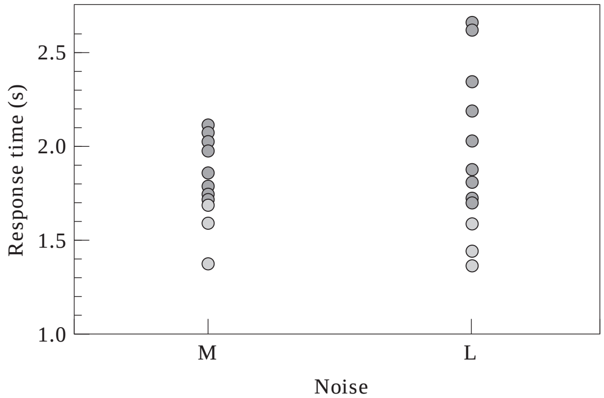

Figure 8. The average value of the individual response time for the secondary task during Test II.

can thus be seen as a time scale, and the test subjects took an average about four minutes to answer each block. Figure 7 may indicate that the response time for the low frequency noise was longer during the last three time periods. If there had been no difference in response time between the noises the average value would have been zero.

For the primary task in test II (the short term reaction time test), no significant differences could be seen between the two noise exposures in response time or number of correct answers. The average value of the individual response time for the secondary task during test II is shown in Figure 8. In Figure 8 it may be observed that the response time for the secondary task during test II was longer for some subjects in the low frequency noise exposure. This difference was however not statistically significant.

No difference was observed for test I in relation to the different noise exposures.

The relation between the subjective estimated interference with performance caused by low frequency noise and the response time for the last three periods during test III was 0·46 (value for 95% significance level is 0·49 Pearson's correlation coefficient). No relation was seen for the mid frequency noise ($r = 0{\cdot}08$). A significant relation was found between reduced activity and performance time during the last three periods of test III for both noises, although this relation was stronger for the low frequency noise, $r = 0{\cdot}79$, $p < 0{\cdot}01$ and $r = 0{\cdot}49$, $p < 0{\cdot}05$ for low and mid frequency noise respectively.

Apart from tiredness, the reported symptoms and effects on mood agreed with earlier findings on effects after exposure to low frequency noise. The subjects reported a feeling of pressure on the head rather than headache and lower social orientation and pleasantness after low frequency noise exposure [7].

5. CONCLUSION

The results showed that the low frequency noise was estimated to interfere more strongly with performance. The results also gave some indications that cognitive demands were less well coped with under the low frequency noise condition. This effect was especially pronounced in the last parts of the tests, which indicates that the effects appear over time. If this effect can be verified in further studies, it could be hypothesized that the low frequency exposure was more difficult to habituate to. The relation between the reduced activity and response time, which was especially pronounced in the low frequency noise condition, may also indicate that increased fatigue was of importance for the results. The underlying mechanisms responsible for reduced performance caused by low frequency noise needs to be furthered studied. The consequences of the effects on mood in a work situation are difficult to postulate, but may be of importance in work situations requiring teamwork and cooperation, and any work requiring interpersonal contacts.

The results further indicate that the NC curves do not fully assess the negative effects of low frequency noise on work performance.

Althought these results are indications of effects seen among a small sample of subjects, they were obtained during a limited period of time and at a level usually considered as acceptable. If the results of the experiment are seen as a consequence of distraction, such that the low frequency noise condition was more distracting, even greater distraction would be anticipated during a longer exposure time and a heavier and perhaps more realistic work in an office environment. It is therefore justified to continue further studies into this area to validate the data from the pilot study and to identify the full consequences of low frequency exposure over a whole working day.

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