

A Study on the Combined Effect of Noise and Vibration on the Performance of a Readability Task in a Mobile Driving Environment by Operators of Different Ages

Iqbal Ahmed Khan

Department of Mechanical Engineering, Krishna Engineering College, Ghaziabad,
Uttar Pradesh, India

**Zulquernain Mallick
Zahid A. Khan**

Mechanical Engineering Department, Jamia Millia Islamia, New Delhi, India

Mohammed Muzammil

Z.H. College of Engineering & Technology, Aligarh Muslim University, Aligarh,
Uttar Pradesh, India

This study investigated the combined effect of noise and vibration on the performance of a readability task in a mobile driving environment by operators of different ages. Subjects performed a readability task on a laptop computer in a sitting posture without their backs supported under varying levels of noise and vibration. Data in terms of a mean number of characters read per minute were collected and statistically analyzed. Results showed that the individual effects of noise, vibration, and operators' age as well as the interaction between operators' age and vibration were statistically significant. However, the combined effect of noise and vibration was not found to be statistically significant. Results also indicated that the operators' age was statistically significant at all levels of vibration and vibration was statistically significant at all levels of operators' age.

noise equivalent acceleration of vibration task performance mobile environment
operator's age

1. INTRODUCTION

People use laptops not only in offices but also when travelling. The use of newer, portable computers by executives and other professionals has increased exponentially, particularly in a real mobile driving environment. Mobile

computing has exposed computer users to various environmental stressors. Notable among them are noise and vibration. Apart from these, other factors like age, gender, sitting posture, etc., may also influence task performance. Studies have shown that low-frequency noise annoyed male operators and should be considered in occupational exposure

assessment [1]. Low-frequency noise at 50 dB(A) could be perceived as annoying and adversely affecting mental performance (concentration and visual perception) of male operators [2]. The presence of low-frequency noise (including infrasonic noise) at workstations in offices caused annoyance among workers who were involved in mental work [3]. Noise negatively influenced carrying out tasks that required focused attention [4]. Many studies also showed the effect of vibration on human performance. For example, McLeod and Griffin showed that whole-body vibration disrupted manual control performance [5]. Sherwood and Griffin suggested that vibration disrupted central cognitive mechanisms utilized during the processing of information in short-term memory [6]. A review of the literature on the subject revealed that though many studies had been conducted in the past to assess the effect of individual environmental stresses, there was little research on the combined effect of noise and vibration in a mobile computing environment. Harris and Shoenberger showed adverse effects on performance when a task was conducted in the presence of combined noise and vibration [7].

After the age of 40 or so everybody's adaptability to the working environment decreases. Also, as people age, their individual differences increase [8]. The operators' age, print quality and illumination level significantly influenced their performance on the visual display units [9].

Keeping this in mind, this study was designed to investigate the combined effect of noise and vibration on the performance of a readability task. Reading materials were presented to male operators of different age groups on the screen of a laptop computer. They performed the task in a sitting posture with their back not supported. The

readability task was performed under varying levels of noise and vibration in a mobile driving environment. The following hypotheses were structured.

1. The varying levels of noise adversely affect the performance of a readability task of male operators of different ages in a mobile driving environment.
2. The equivalent level of vibration acceleration has a negative effect on operators' performance of a readability task.
3. The operators' age has a significant effect on the performance of a readability task.
4. The interaction between operators' age and the equivalent level of vibration acceleration has a significant effect on the performance of a readability task.
5. The interaction between operators' age and noise significantly affects the performance of a readability task.
6. The combined effect of noise and vibration significantly affects operators' performance of a readability task.
7. The interaction between operators' age, noise, and equivalent level of vibration acceleration has a significant effect on the performance of a readability task.

2. METHOD

2.1. Subjects

Seven male right-handed subjects each from age groups A_1 (25 years old and more but under 35), A_2 (35 years old and more but under 45) and A_3 (45 years old and more but under 55) participated in this study. The subjects were randomly selected from postgraduate or doctoral university students

TABLE 1. Subjects' Age, Height and Weight

Age Group	Age (years)		Height (m)		Weight (kg)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
A_1	28.3	3.23	1.78	0.0553	60.5	6.56
A_2	38.4	4.12	1.67	0.0432	64.8	5.28
A_3	52.2	3.01	1.70	0.0233	56.3	3.87

Notes. $25 \leq A_1 < 35$ years old, $35 \leq A_2 < 45$ years old, $45 \leq A_3 < 55$ years old.

and from employees. The average computer working experience of employees in age groups A₂ and A₃ was ~15 and ~30 years, respectively. The subjects agreed to participate in the study voluntarily without any remuneration. All of them had normal vision, normal hearing and no previous history of neuromuscular disorders. None of them had any knowledge of French. The means and standard deviation of age, height and weight of the subjects are shown in Table 1. All the experimental sessions were held between 9.00 a.m. and 1.00 p.m.

2.2. Experimental Setup

Experimental investigations were carried out in a vehicle (Maruti-Omni van, Japan), which was structured as a real mobile research unit. The unit comprised of the following subsystems (Figure 1):

- a laptop (Armada 1500, Compaq, USA); the subjects maintained a screen angle of 120°;
- a sound level meter (GA 214, Castle Group Ltd., UK);
- a vibration level meter (VR 5100, Ono Sokki Co. Ltd., Japan);

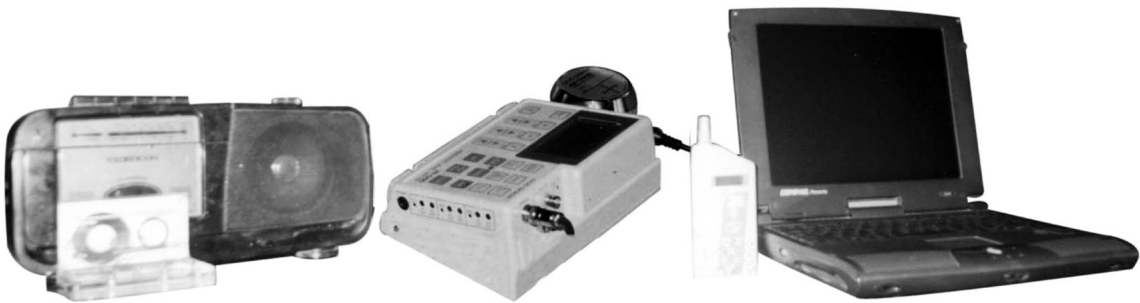


Figure 1. Equipment used in the experimental setup.

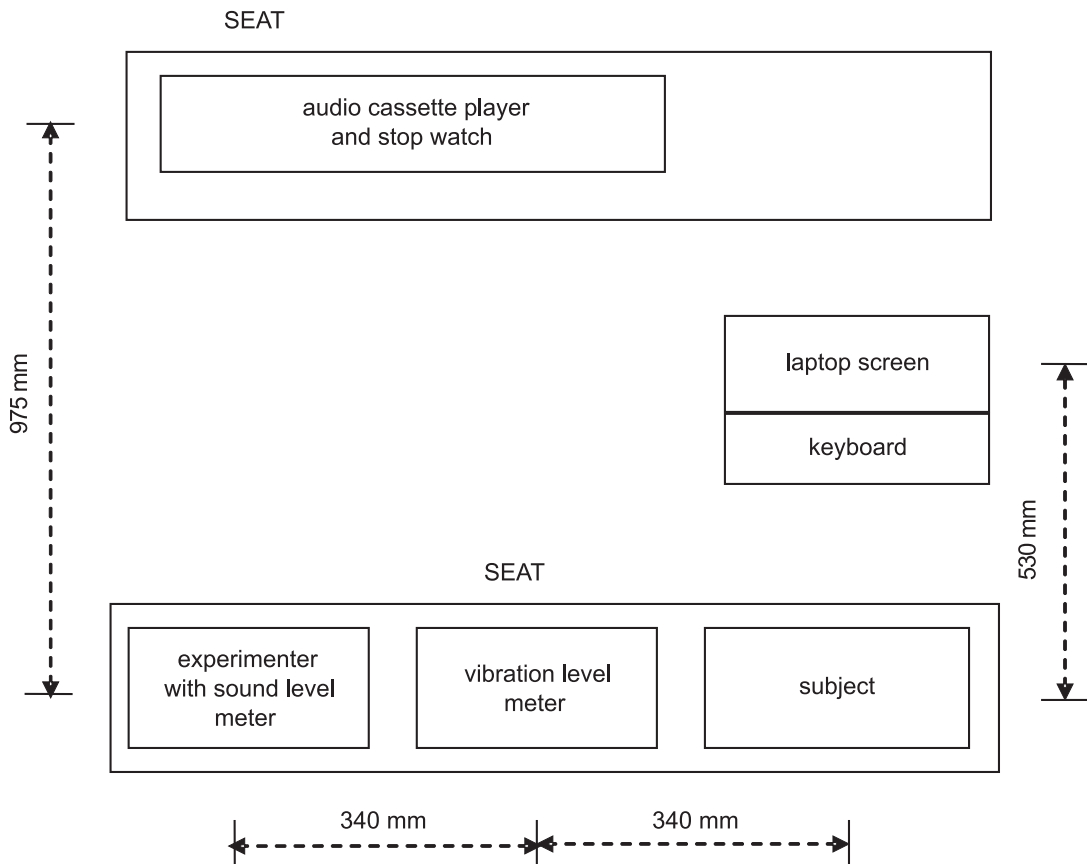


Figure 2. Schematic diagram of the experimental setup.



Figure 3. Male operator performing a readability task on a laptop screen without back support.

- an audio cassette player with cassettes;
- reading material in French; the font was Times New Roman, regular, 14 points, with automatic (black) color; characters had normal spacing; the screen had a red background. Red was chosen in light of Hatta, Yoshida, Kawakami, et al.'s [10] study which found a significant effect of a red screen on operators' performance of a visual task.

Figure 2 is a schematic diagram of the experimental setup. The operators suggested the distances in this figure since they were able to perform the assigned task comfortably when the subsystems were thus located. It may be noted that the laptop was on the lap of the subjects while they were performing the readability task and the distance from the subject to the laptop screen in Figure 2, in fact represents the distance from the subject's eye (Figure 3) to the center of the screen. Arrangements were also made to avoid screen glare. The subjects maintained a sitting posture without a backrest.

2.3. General Experimental Procedure

The following preparatory steps were undertaken before the actual experiment.

1. Each subject was briefed about the objective of the experiment.
2. Instructions were given to the subjects.

3. Training sessions were organized for subjects to become familiar with the task.
4. To avoid any learning effect, four different texts in French (rather than English) were provided to the subjects. The fact that the texts were in French minimized the difference between the subjects whose proficiency in English varied.

The subject received the instructions while he was sitting in the mobile research unit. Subsequently, the following steps were taken, in both the training and experimental sessions.

1. The reading material in French written in the Latin alphabet was presented on a full screen of the laptop to the subject by the experimenter.
2. A START signal was given to the subject to start the readability task at a normal pace.
3. The subjects performed the readability task for 20 min; task performance was measured in terms of the mean number of characters read per minute (MNC RPM).
4. After 20 min of work, a STOP signal was given to indicate the end of the task.

The experiments were conducted under varying levels of noise and equivalent vibration. The selected levels of noise L_{cq} were 80, 90, and 100 dB(A). The equivalent level of vibration was also taken at three levels (0.45, 0.94, and 1.71 m/s^2).

The total equivalent acceleration of vibration was calculated as per Standard No. ISO 2631-1:1997 [11]. During the experimental task, the levels of equivalent noise and vibration in the mobile environment were kept at a prespecified value by constantly monitoring. The prespecified levels of noise were maintained by manipulating the volume regulator of the audio cassette player and they were measured near the ear of the subjects. The level of vibration was also kept the same in the x , y and z directions by manipulating the speed of the vehicle. The average time for each experimental session was of the order of 20 min. A rest period of 30 min was provided to the subjects before another set of experiments was carried out.

2.4. Statistical Analysis

A three-factor analysis of variance (ANOVA) was carried out to determine the effects of the parameters under investigation. The independent variables were the operators' age group (A_1 , A_2 , A_3), noise L_{cq} (80, 90, 100 dB(A)) and equivalent acceleration of vibration (0.45, 0.94, 1.71 m/s^2). The dependent variable was performance of a readability task (measured in terms of MNCRPM).

2.5. Noise Recording and Measurement

Road traffic noise was recorded with an audio cassette recorder/player. During experimental sessions noise level L_{cq} was maintained at prespecified levels by adjusting the volume knob of the audio cassette player. The equivalent level of noise was measured with a sound level meter. The sound level meter was calibrated prior and after the measurements. The measuring level range of the equipment and the measuring frequency range (including the microphone) were 35–140 dB(A) and 20–8000 Hz, respectively.

2.6. Vibration Measurement

The vibration level meter based on Japanese Industrial Standard [12] and the measurement law of Japan was used to measure the equivalent level of vibration acceleration in the x , y and z directions. The vibration pickup (NP-7210, Ono Sokki, Japan) with three independent shear type piezoelectric elements for detecting signals were

placed on the seat of the Maruti-Omni van on a specially prepared hard disk as per Standard No. ISO 2631-1:1997 [11]. The vibration acceleration levels were measured with respect to the standard biodynamic co-ordinate system according to the standard. The vibration level meter was calibrated in the x , y and z directions prior to measurements. The measuring level range of the equipment and the measuring frequency range were 30–120 dB(A) and 1–90 Hz, respectively. To check the suitability of the basic evaluation method, the crest factor was calculated for the x , y and z directions. The crest factor is defined as the modulus of the ratio of the maximum instantaneous peak value of the frequency weighted acceleration signal to its root-mean-square (rms) value. The peak shall be determined over the duration of measurement. The crest factor values obtained for the x , y and z directions were within the limit prescribed by the standard. As per recommendations, for vibration with crest factors ≤ 9 , the basic evaluation method is normally sufficient.

3. RESULTS

This study investigated the combined effect of noise and vibration on the performance of male operators of different ages of a readability task on a laptop screen in a mobile driving environment. The results of an ANOVA carried out on the data collected showed that the effect of noise, vibration and operators' age were statistically significant (Table 2). This indicated that the performance of a readability task on a laptop screen in the mobile driving environment was not independent of noise, vibration and age. Also, the interaction between the operators' age and vibration was significant (Table 2). The significant interaction of the operators' age and vibration necessitated an analysis of simple main effects.

The results of the simple main effects analysis (Table 3) indicated that the operators' age was significant at all three levels of vibration and also that vibration was statistically significant at all three age groups of the operators. The results of ANOVA presented in Table 2 also revealed that the interaction between the operators' age and noise, the combined effect of noise and vibration

TABLE 2. ANOVA Results When Operators of Different Ages Performed a Readability Task on a Laptop Screen in a Mobile Environment

Source of Variation	df	MS	F	p
Between subjects	20	—	—	
Operators' age	2	5291.45	6.16	.0001
Subjects within groups (error I)	18	859.69	—	
Within subjects	168	—	—	
Noise level	2	4235.23	101.56	.0001
Operators' age × noise	4	60.01	1.44	.0543
Noise × subjects within groups (error II)	36	41.70	—	
Vibration	2	2187.63	104.32	.0001
Operators' age × vibration	4	126.04	6.01	.0027
Vibration × subjects within groups (error III)	36	20.97	—	
Noise × vibration	4	4.91	1.30	.3447
Operators' age × noise × vibration	8	5.31	1.41	.2071
Noise × vibration × subjects within groups (error IV)	72	3.77	—	
Total	188	—	—	

Notes. Vibration—equivalent acceleration of vibration level.

TABLE 3. Analysis of a Simple Main Effect of Subjects (of Different Age Groups) Performing a Readability Task on a Laptop Screen Under Varying Levels of Equivalent Acceleration of Vibration in a Mobile Environment

Source of Variation	df	MS	F	p
Age group at				
vibration level ₁ (0.45 m/s ²)	2	2656.63	126.69	.0001
vibration level ₂ (0.94 m/s ²)	2	1964.68	93.69	.0001
vibration level ₃ (1.71 m/s ²)	2	922.23	43.98	.0001
Vibration at				
age group A ₁	2	1570.53	74.89	.0001
age group A ₂	2	464.31	22.14	.0001
age group A ₃	2	404.87	19.31	.0001

Notes. Vibration—equivalent acceleration of vibration level; 25 ≤ A₁ < 35 years old, 35 ≤ A₂ < 45 years old, 45 ≤ A₃ < 55 years old.

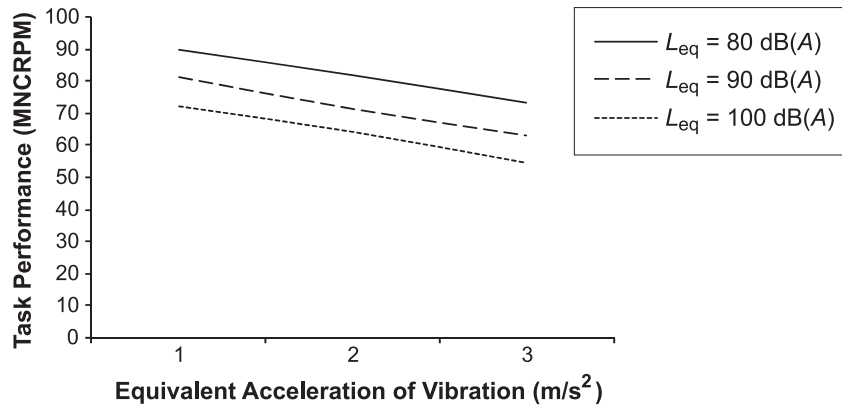


Figure 4. Relationship between task performance and equivalent acceleration of vibration at different noise levels for operators in age group A₁. Notes. 25 ≤ A₁ < 35 years old, L_{eq}—noise level.

as well as the interaction between the operators' age, noise and vibration did not produce a significant effect on computer operators' performance of a readability task.

Figures 4–7 show the relationship between task performance for operators' age groups A_1 , A_2 , A_3 and all the three age groups and vibration acceleration at different noise levels. An almost

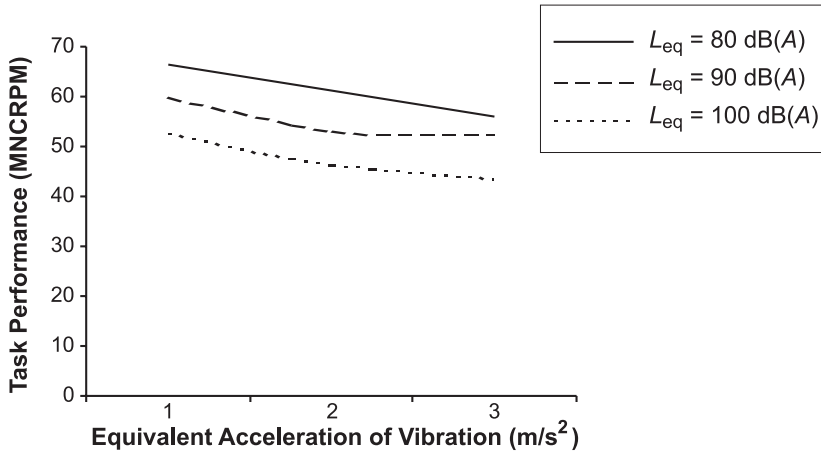


Figure 5. Relationship between task performance and equivalent acceleration of vibration at different noise levels for operators in age group A_2 . Notes. $35 \leq A_2 < 45$ years old, L_{eq} —noise level.

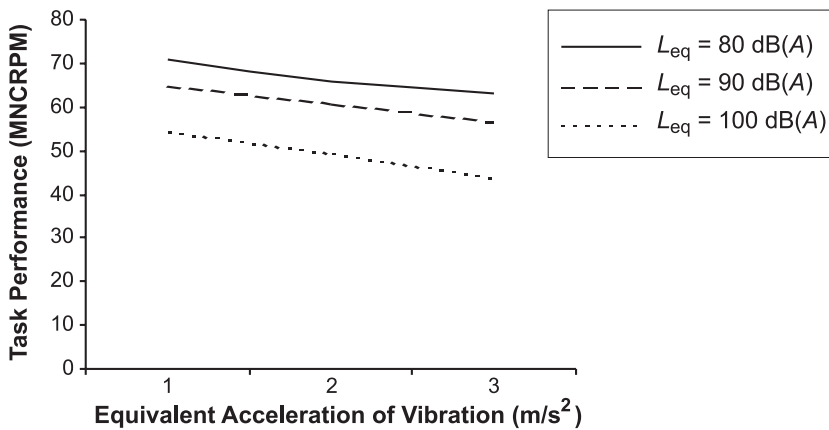


Figure 6. Relationship between task performance and equivalent acceleration of vibration at different noise levels for operators in age group A_3 . Notes. $45 \leq A_3 < 55$ years old, L_{eq} —noise level.

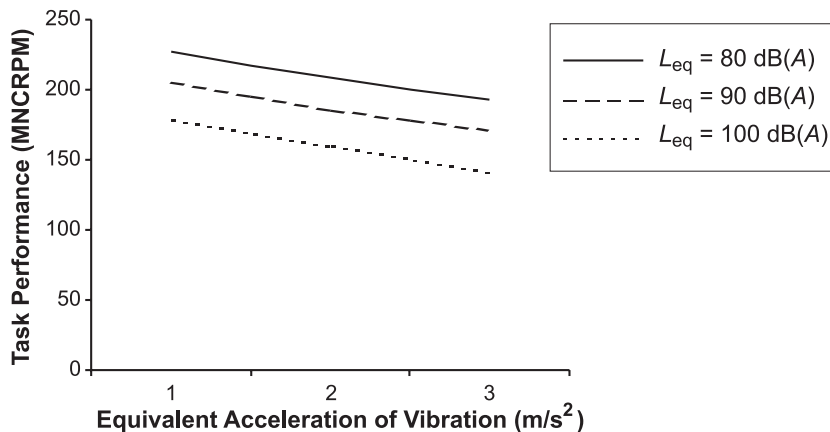


Figure 7. Relationship between task performance and equivalent acceleration of vibration at different noise levels for operators in all age groups. Notes. L_{eq} —noise level.

linear relationship can be seen in these figures. The governing equations for task performance of different age groups of operators versus vibration acceleration levels for varying noise levels were obtained using a simple linear regression analysis. In the governing equations TP_1 , TP_2 and TP_3 represent task performance at varying levels of noise and V is the value of equivalent acceleration of vibration, which represents the level of total vibration.

The task performance model for operators' age group A_1 for varying noise levels (Figure 4) was obtained as follows:

1. for $L_{\text{eq}} = 80 \text{ dB(A)}$, $TP_1 = 94.8 - 12.8 V$; (1)
2. for $L_{\text{eq}} = 90 \text{ dB(A)}$, $TP_2 = 86.1 - 14.0 V$; (2)
3. for $L_{\text{eq}} = 100 \text{ dB(A)}$, $TP_3 = 77.8 - 13.8 V$. (3)

The task performance model for operators' age group A_2 for varying noise levels (Figure 5) was obtained as follows:

1. for $L_{\text{eq}} = 80 \text{ dB(A)}$, $TP_1 = 69.7 - 8.18 V$; (4)
2. for $L_{\text{eq}} = 90 \text{ dB(A)}$, $TP_2 = 61.2 - 5.75 V$; (5)
3. for $L_{\text{eq}} = 100 \text{ dB(A)}$, $TP_3 = 55.1 - 7.15 V$. (6)

The task performance model for operators' age group A_3 for varying noise levels (Figure 6) was obtained as follows:

1. for $L_{\text{eq}} = 80 \text{ dB(A)}$, $TP_1 = 72.6 - 5.82 V$; (7)
2. for $L_{\text{eq}} = 90 \text{ dB(A)}$, $TP_2 = 67.5 - 6.37 V$; (8)
3. for $L_{\text{eq}} = 100 \text{ dB(A)}$, $TP_3 = 57.7 - 8.31 V$. (9)

The task performance model (all age groups) for varying noise levels (Figure 7) was obtained as follows:

1. for $L_{\text{eq}} = 80 \text{ dB(A)}$, $TP_1 = 237 - 26.8 V$; (10)
2. for $L_{\text{eq}} = 90 \text{ dB(A)}$, $TP_2 = 215 - 26.1 V$; (11)
3. for $L_{\text{eq}} = 100 \text{ dB(A)}$, $TP_3 = 191 - 29.2 V$. (12)

4. DISCUSSION

The hypotheses listed in section 1 were tested using ANOVA. The first four hypotheses turned out to be valid, whereas the last three did not. This study found that the operators' performance of a readability task in the mobile environment in the presence of noise deteriorated. This might be because the noise produces a kind of hammering

action on the processing resources. As a consequence, operators lose their concentration, are disturbed and annoyed. This finding is supported by many studies. Boman, Enmarker and Hygge showed effects of noise sources on a majority of the dependent measures, both when taken alone and aggregated according to the nature of the material to be memorized by the subjects of four age groups (13–14, 18–20, 35–45 and 55–65) [13]. However, they found that the noise effects for episodic memory tasks were stronger than for semantic memory task. Hygge, Boman and Enmarker showed that both road traffic noise and meaningful irrelevant speech impaired recall of the text [14]. They also found that the retrieval in noise from semantic memory was impaired. Khan, Mallick and Khan found that males' and females' performance of a readability task was impaired in the presence of road traffic noise in a mobile driving environment [15].

Another important finding of the present study is that whole-body vibration affects negatively operators' performance of a readability task. The impact of vibration might disturb the operators' visual performance. Vibration might make proper recognition of characters on the screen of the laptop difficult. As a result performance is decreased. This finding is also supported by many studies. Ishitake, Ando, Miyazaki, et al. showed that the disturbances of visual performance depended on vibration frequency with a maximum reduction in visual acuity at a frequency of 12.5 Hz [16]. According to Griefahn, Brode and Jaschinski participants 19–26 years old faced difficulty in properly recognizing characters and graphic patterns containing horizontal lines and developed asthenopic complaints in the presence of 5 Hz sinusoidal single and dual axes (vertical and lateral) whole-body vibration [17]. Khan et al. found that males' and females' performance of a readability task was significantly affected by whole-body vibration present in a mobile driving environment [15].

The operators' age had a significant effect on the performance of the readability task. The performance of the readability task by subjects in the A_1 age group was best. The performance of A_2 subjects deteriorated and the performance of

A₃ subjects improved as compared to the subjects in the A₂ age group. This might be because the A₃ subjects had longer working experience on computer and they concentrated more on their assigned task to compensate for age-related deficiencies. This finding was not supported by previous studies available in the literature. Thus, the effect of the age on operators' performance of visual tasks needs to be further investigated to come to a general conclusion.

Further, interaction between operators' age and vibration was found to be significant in the present study. The result of a simple main effect analysis for this significant interaction showed that the operators' age was significant for all three levels of vibration and that equivalent acceleration of vibration was also significant for all three age groups. Factors, such as vibration of laptop screen and operators' eyes at different frequencies, uncomfortable sitting posture, and an unergonomically designed laptop might be the reasons for this result. Consequently, there was a time lag in tracking the stimuli presented to the operators on the laptop screen; hence their performance of the readability task decreased. The authors could not find studies in support of this finding in the literature.

One of the major findings of the present study was that the combined effect of noise and vibration did not affect the operators' performance of a readability task. This finding is supported by Ljungberg and Neely [18] who also reported that relatively short exposure to noise and vibration typical of that found in industrial vehicles did not significantly affect performance of cognitive tasks or saliva cortisol levels even if work in those environments was more difficult or stressful. The finding is also supported by Khan et al. [15], who observed that the combined effect of noise and vibration did not affect either males' or females' performance of a readability task in a mobile driving environment.

5. CONCLUSIONS

On the basis of the results of this study, the following conclusions were drawn:

- noise has a significant effect on the performance of a readability task in a mobile environment when the task is performed by operators of different ages;
- vehicular vibration has a significant negative effect on the performance of a readability task in a mobile environment when the task is performed by operators of different ages;
- the organismic variable, operators' age, has a significant negative effect on the performance of a readability task in a mobile driving environment;
- the interaction between operators' age and vibration is statistically significant;
- the interaction between operators' age and noise is statistically insignificant for the readability task considered in this study;
- the combined effect of noise and vibration does not have a significant effect on the performance of a readability task by computer operators of different ages;
- the interaction between operators' age, noise and vibration was statistically insignificant for the readability task considered in this study.

The findings of the present study suggest that designers and manufacturers of computing systems to be used in public transport (trains, buses) as well as private cars (GPS, radio/cassette player, etc.) and other vehicles should take into consideration the organismic and environmental variables that affect the operational capability of end users, specifically in a mobile driving environment.

REFERENCES

1. Pawlaczyk-Łuszczynska M, Dudarewicz A, Waszkowska M, Śliwińska-Kowalska M. Assessment of annoyance from low frequency and broad band noises. *Int J Occup Med Environ Health*. 2003; 16(4):337–43.
2. Pawlaczyk-Łuszczynska, Dudarewicz A, Waszkowska M, Szmczak W, Kameduła M, Śliwińska-Kowalska M. The effect of low frequency noise on human mental performance. *Med Pr*. 2004;55(1):63–74. In Polish, with an abstract in English.

3. Kaczmarska A, Łuczak A. A study of annoyance caused by low-frequency noise during mental work. *International Journal of Occupational Safety and Ergonomics (JOSE)*. 2007;13(2):117–25.
4. Smith AP. Noise and aspects of attention. *Brit J Psychol*. 1991;82:313–24.
5. McLeod RW, Griffin MJ. A review of the effects of transactional whole-body vibration on continuous manual control performance. *JSV*. 1989;133:55–115.
6. Sherwood N, Griffin MJ. Effects of whole-body vibration on short-term memory. *Aviat Space Environ Med*. 1990;61(12):1092–7.
7. Harris CS, Shoenberger RW. Combined effects of broadband noise and complex waveform vibration on cognitive performance. *Aviat Space Environ Med*. 1980;51(1):1–5.
8. Yokomizo Y. Measurement of ability of older workers. *Ergonomics*. 1985;28:843–54.
9. Smith SW, Rea MS. Proof reading under different levels of illumination. *J Illum Eng Soc*. 1978;10:47–52.
10. Hatta TI, Yoshida H, Kawakami A, Okamoto M. Color of computer display frame in work performance, mood and physiological response. *Percept Mot Skills*. 2002;94(1):39–46.
11. International Organization for Standardization (ISO). Mechanical vibration and shock-evaluation of human exposure to whole-body vibration—part1: general requirements (Standard No. ISO 2631-1:1997). Geneva, Switzerland: ISO; 1997.
12. Japanese Industrial Association (JIA). Vibration level meters (Standard No. JIS C 1510:1976). Tokyo, Japan; JIA; 1976.
13. Boman E, Enmarker I, Hygge S. Strength of noise effects on memory as a function of noise and age. *Noise Health*. 2005;7(27):11–26.
14. Hygge S, Boman E, Enmarker I. The effects of road traffic noise and meaningful irrelevant speech on different memory systems. *Scand J Psychol*. 2003;44(1):13–21.
15. Khan IA, Mallick Z, Khan ZA. A study on the combined effect of noise and vibration on operators' performance of a readability task in a mobile driving environment. *International Journal of Occupational Safety and Ergonomics (JOSE)*. 2007;13(2):127–136.
16. Ishitake T, Ando H, Miyazaki Y, Matoba F. Changes of visual performance induced by exposure to whole-body vibration. *Kurume Med J*. 1998;45(1):59–62.
17. Griefahn B, Brode P, Jaschinski W. Contrast thresholds and fixation disparity during 5 Hz sinusoidal single-and dual axis (vertical and lateral) whole-body vibration. *Ergonomics*. 2000;43(3):317–32.
18. Ljungberg JK, Neely G. Stress, subjective experience and cognitive performance during exposure to noise and vibration. *J Environ Psychol*. 2007;27(1):44–54.