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

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This paper presents a study in which the main objective was to investigate the combined effect of noise and vibration on the performance of a readability task in a mobile driving environment. Subjects performed a readability task on a laptop computer in a sitting posture with their backs supported with a backrest under varying levels of noise and vibration. The data in terms of the mean number of characters read per minute were collected and statistically analyzed. Results showed that the individual effect of noise, vibration, and the operators' gender as well as the interaction between gender and noise, and gender and vibration were statistically significant. However, the combined effect of noise and vibration was not found to be statistically significant. Results also indicated that gender was statistically significant at all levels of noise as well as vibration, and noise and vibration were statistically significant at both levels of gender.

noise   equivalent acceleration of vibration   task performance   mobile environment

1. INTRODUCTION

The use of newer and portable versions of computers by executives and other professionals in a mobile environment has increased manifold in recent times. Mobile computing has exposed the operators to various environmental stresses. Notable among them are noise and vibration. Apart from these, other factors like sitting posture, gender, age, etc., may influence the operators' task performance. Studies have shown that short-term whole-body vibration exposure could affect visual performance, depending on the vibration frequency and the sitting posture [1]. Manual control performance was also found to be disrupted due to whole-body vibration [2]. Visual cortical activity has been shown to diminish substantially when the subjects were exposed to loud acoustic sound [3]. Noise negatively influenced performance in carrying out tasks that required focused attention

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[4]. Literature reviewed on the topic revealed that though many studies have been conducted in the past to assess the effect of environmental stresses separately, there was little research on the combined effect of noise and vibration in a mobile computing environment. Harris and Shoenberger [5] showed adverse effects on performance when a task was conducted in the presence of combined noise and vibration. Noise and vibration could adversely affect subjective operator workload without affecting objective task performance [6]. As far as the effect of posture was concerned, whole-body vibration was found to have a significant effect on seated subjects [7]. The psychological responses of humans to whole-body vibration were also found to be affected greatly by their posture [8]. Combined exposure to noise and vibration could lead to an increased instability of the body's upright posture. Hinz, Seidel, Menzel, et al. [9] observed that backrest contact and posture should be an important factor for an assessment of whole-body vibration. Working on a video display unit (VDU) was found to be more taxing for females than for males [10] as the former showed greater prevalence of musculoskeletal symptoms. Keeping this in mind, the present study was designed to investigate the combined effect of noise and vibration on the performance of a readability task where reading materials were presented to the operators on the screen of a laptop computer and the operators performed the task in a sitting posture with their back supported with a back support. The readability task was performed by the operators under varying levels of noise and vibration in a mobile driving environment. The following hypotheses were formulated:

1. The varying levels of noise adversely affected the performance of a readability task of male and female operators in a mobile driving environment.
2. The equivalent level of vibration acceleration had a negative affect on the operators' performance of a readability task.
3. Gender (male and female) had a significant effect on the performance of a readability task.
4. The interaction between gender and noise significantly affected the operators' performance of a readability task.
5. The interaction between gender and equivalent level of vibration acceleration had a significant effect on the operators' performance of a readability task.
6. The combined effect of noise and vibration significantly affected the operators' performance of a readability task.
7. The interaction between gender, noise, and equivalent level of vibration acceleration had a significant effect on the operators' performance of a readability task.

2. METHOD

2.1. Subjects

Fourteen subjects (7 males and 7 females) participated in this study. Their age ranged from 22 to 32 years (M = 26, SD = 4.9). All the subjects had normal vision with no previous history of neuromuscular disorder.

2.2. Experimental Setup

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

- a laptop (Armada 1500, Compaq, USA); a screen angle of 120° was maintained by the subjects;
- a sound level meter (GA 214, Castle Group Ltd., UK);
- a vibration level meter (VR 5100, Ono Sokki Co. Ltd., Japan);
- an audio cassette player with cassettes;
- reading material in French; the font was Times New Roman, regular, 14 in size with automatic color; characters had normal spacing; the screen had a red background;

The subjects maintained a sitting posture with a backrest.

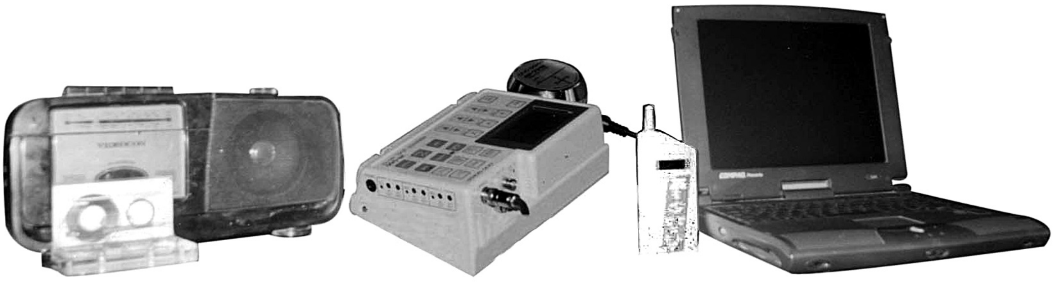

Figure 1. Equipment used in the experimental setup.

Figure 2 shows a schematic diagram of the experimental setup in which placement of the subsystems and distances between them are depicted. The distances shown in this figure were suggested by the operators since they were able to perform the assigned task comfortably when the subsystems were placed at these distances. It may be noted that the laptop was kept on the lap of the subjects while they were performing the readability task and the distance from the subject to the laptop screen shown in Figure 2, in fact represents the distance from the subject's eyes (Figure 3) to the center of the laptop screen. Further, arrangements were also made to avoid screen glare.

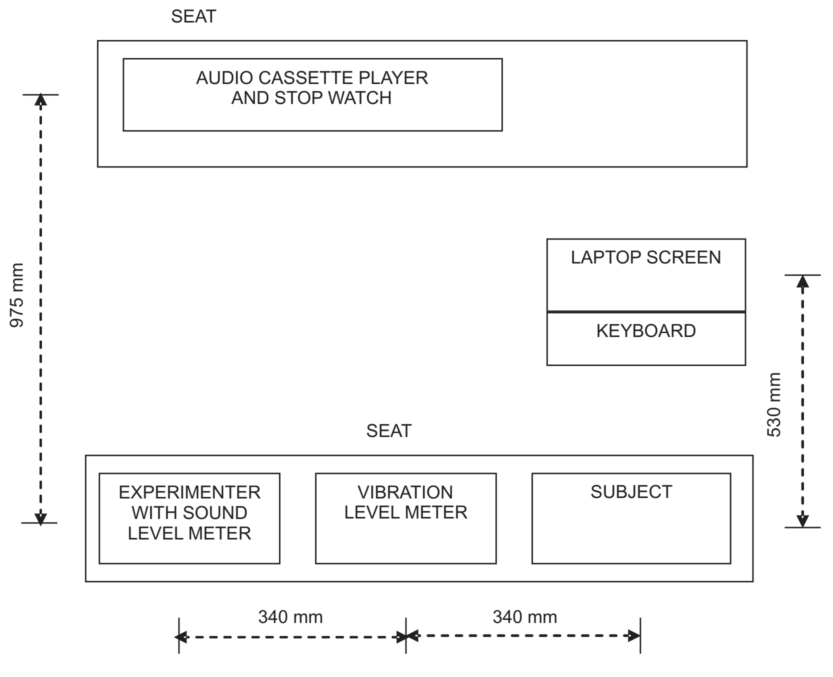

Figure 2. Schematic diagram of the experimental setup.

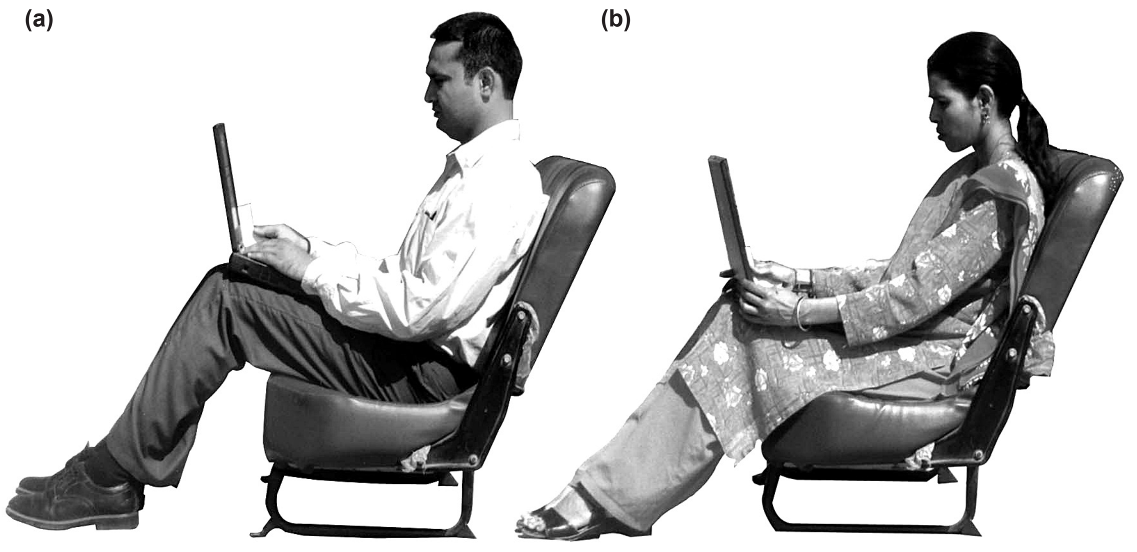

Figure 3. (a) Male and (b) female operators performing a readability task on laptops with their backs supported with a backrest of the seats.

2.3. General Experimental Procedure

The following preparatory steps were undertaken before performing the actual experiment.

1. Each subject was briefed about the objective of the experiment.
2. Instructions to be followed while performing the experimental task were given to the subjects.
3. Training sessions were organized for subjects in order to get them familiarized with the task to be performed.

The subject took his/her seat in the mobile research unit and all the instructions were given. Subsequently, the following steps were taken, in that order, for both the training and experimental sessions.

1. The reading material in French written in the Latin alphabet was presented on the screen of the laptop to the subject by the experimenter.
2. A START signal was given to the subject to start the readability task.
3. The subjects performed the readability task for 20 min and task performance was measured in terms of the mean number of characters read per minute (MNCRPM) by the subject.
4. A STOP signal was given to the subjects to indicate to them the end of the readability task.

The experiments were conducted under varying levels of noise and equivalent vibration. The selected levels of noise L_{eq} 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). While the experimental task was performed, 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.

2.4. Noise and Vibration Levels

A pilot study was carried out to determine the different levels of equivalent noise and vibration acceleration in the *x*, *y* and *z* directions to which operators were subjected while moving in the driving environment. It was observed that noise level L_{eq} varied from 80 to 100 dB(A) and the level of equivalent vibration was between 0.45 and 1.71 m/s^2. The total equivalent acceleration of vibration was calculated as per the recommendations of Standard No. ISO 2631-1:1997 [11]. In light of this discussion, three equivalent levels of noise L_{eq}, i.e., 80, 90 and 100 dB(A) and three equivalent levels of acceleration of vibration were set at 0.45, 0.94 and 1.71 m/s$^{2.}$

2.5. Task Performance

Subjects read the material (French text written in the Latin alphabet) presented to them on a laptop screen as per the instructions given to them. The operator's MNCRPM was taken as a measure of task performance. It was ensured that the subject did not commit mistakes of any kind.

2.6. Stimuli and the Experimental Task

A stimulus in the form of text was presented to the subjects on a full screen of the laptop. The text presented has no literal meaning. It was in French. To avoid any learning effect, four different texts in French were provided to them. This feature minimized the difference between subjects from the view point of proficiency in English.

2.7. Statistical Analysis

A three-factor ANOVA was carried out to determine the effects of parameters under investigation. The independent variables taken were organismic variable gender (male and female), noise L_{eq} (80, 90 and 100 dB(A)) and vibration (0.45, 0.94 and 1.71 m/s^2). The dependent variable was performance of a readability task, which was measured in terms of MNCRPM.

2.8. Noise Recording and Measurement

Road traffic noise was recorded on a cassette through an audio cassette recorder/player. During experimental sessions noise level L_{eq} was maintained at three levels, i.e., 80, 90 and 100 dB(A) by regulating the volume knob of the cassette player. The measurement of the equivalent level of noise was done with the help of a sound level meter (GA 214, Castle Group Ltd., UK). The sound level meter was calibrated prior to the measurements. The measuring level range of the equipment and the measuring frequency range (including the microphone) were 35 to 140 dB(A) and 20 Hz to 8 kHz.

2.9. Vibration Measurement

A vibration level meter (VR 5100, Ono Sokki Co. Ltd., Japan) based on a Japanese industrial standard [11] and the measurement law of Japan was used to measure the equivalent level of vibration acceleration in the x, y and z directions. A vibration pickup (NP-7210, Ono Sokki) with three independent shear-type piezoelectric elements for detecting signals was placed on the seat of the Maruti van on a specially prepared hard disk as per the recommendations of Standard No. ISO 2631-1:1997 [12]. 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 to 120 dB and 1 to 90 Hz respectively. To check the suitability of the basic evaluation method, the crest factor was calculated for the x, y and z directions. According to ISO 2631-1:1997, 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 below or equal to 9, the basic evaluation method is normally sufficient.

3. RESULTS

In this study, the combined effect of noise and vibration on male and female operators' performance of a readability task on a laptop screen in a mobile driving environment was investigated. The results of ANOVA carried out on the data collected showed that the effect of noise, vibration, and gender were statistically significant, gender significantly interacted with noise, and also the interaction of gender with vibration was found to be statistically significant (Table 1). The significant interaction between gender and noise, and gender and vibration necessitated an analysis of simple main effects. The results of the simple main effects analysis (Table 2) indicated that gender was statistically significant at all three levels of noise and also noise was statistically significant at both levels of gender. The result of the simple main effects analysis presented

TABLE 1. ANOVA Results When Operators Performed a Readability Task on a Laptop Screen in a Mobile Environment

Source of Variation	*df*	*MS*	*F*	*p*
Between Subjects	13	—	—	—
Gender	1	9212.63	13.34	.0033
Subjects within groups (error I)	12	690.53	—	—
Within Subjects	112	—	—	—
Noise level	2	3834.3	49.96	.0001
Gender × Noise	2	1002.94	13.06	.0001
Noise × Subjects within groups (error II)	24	76.75	—	—
Vibration	2	2584.33	137.24	.0001
Gender × Vibration	2	139.18	7.39	.0032
Vibration × Subjects within groups (error III)	24	18.83	—	—
Noise × Vibration	4	1.46	0.14	.9665
Gender × Noise × Vibration	4	23.61	2.23	.0796
Noise × Vibration × Subjects within groups (error IV)	48	10.57	—	—
Total	125	—	—	—

Notes. Vibration—equivalent acceleration of vibration level.

TABLE 2. Analysis of Simple Main Effect of Subjects (Male and Female) Performed a Readability Task on a Laptop Screen Under Varying Levels of Noise in a Mobile Environment

Source of Variation	*df*	*MS*	*F*	*p*
Gender at				
Noise level$_1$ L_{eq} = 80 dB(A)	1	7424.1	96.73	.0001
Noise level$_2$ L_{eq} = 90 dB(A)	1	3270.1	46.61	.0001
Noise level$_3$ L_{eq} = 100 dB(A)	1	524.4	6.83	.0015
Noise level at				
G_1 (male)	2	4374.75	57	.0001
G_2 (female)	2	426.5	6.03	.0076

TABLE 3. Analysis of Simple Main Effect of Operators (Male and Female) Performed 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*
Gender at				
Vibration level$_1$ (0.45 m/s^2)	1	2114	112.26	.0001
Vibration level$_2$ (0.94 m/s^2)	1	1739	92.35	.0001
Vibration level$_3$ (1.71 m/s^2)	1	892.45	47.39	.0001
Vibration				
G_1 (male)	2	1952.8	103.7	.0001
G_2 (female)	2	770.7	40.93	.0001

Notes. Vibration—equivalent acceleration of vibration level.

in Table 3 showed that the interaction between gender and equivalent acceleration of vibration was statistically significant at all three levels of vibration and vibration emerged to be statistically significant for both males and females. The results of ANOVA presented in Table 1 also revealed that the combined effect of noise and vibration as well as the interaction between gender, noise and vibration did not produce a significant effect on computer operators' performance of a readability task.

Figures 4, 5 and 6 show the relationship between task performance for males, females and both males and females and vibration acceleration at different noise levels. An almost linear relationship can be seen in these figures.

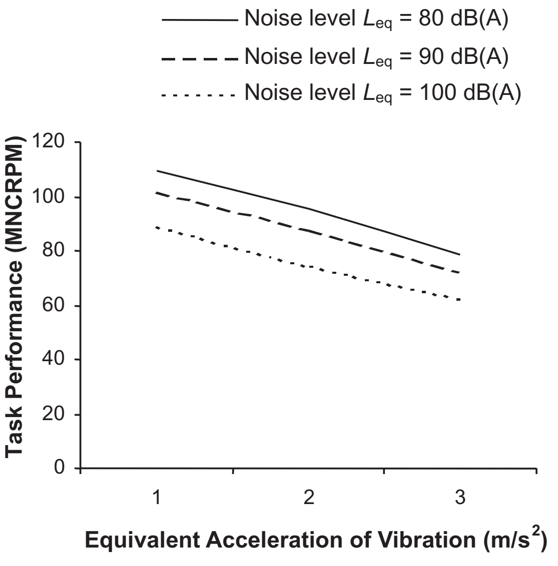

Figure 4. Relationship between task performance and equivalent acceleration of vibration at different noise levels for male operators. *Notes.* MNCRPM—mean number of characters read per minute.

The governing equations for task performance of male operators versus vibration acceleration level for varying noise levels were obtained using a simple linear regression analysis:

1. for L_{eq} = 80 dB(A), TP_1 = 120.33 – 10.1 V; (1)
2. for L_{eq} = 90 dB(A), TP_2 = 106.93 – 10.6 V; (2)
3. for L_{eq} = 100 dB(A), TP_3 = 87.17 – 7.95 V; (3)

where 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 females for varying noise levels (Figure 5) was obtained as follows:

1. for L_{eq} = 80 dB(A), TP_1 = 85.9 – 6.2 V; (4)
2. for L_{eq} = 90 dB(A), TP_2 = 77.77 – 4.85 V; (5)
3. for L_{eq} = 100 dB(A), TP_3 = 78.4 – 7.1 V; (6)

where 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 represents the level of total vibration.

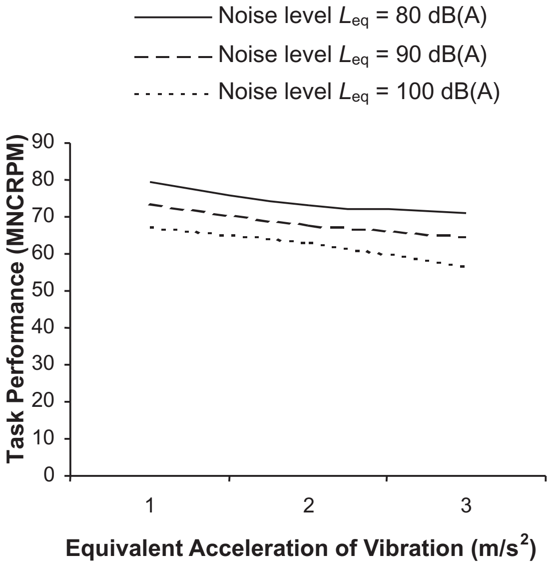

Figure 5. Relationship between task performance and equivalent acceleration of vibration at different noise levels for female operators. *Notes.* MNCRPM—mean number of characters read per minute.

The task performance model (both male and female subjects) for varying noise levels (Figure 6) was obtained as follows:

1. for L_{eq} = 80 dB(A), TP_1 = 206.23 – 16.3 V; (7)
2. for L_{eq} = 90 dB(A), TP_2 = 184.7 – 15.45 V; (8)
3. for L_{eq} = 100 dB(A), TP_3 = 165.75 – 15.05 V; (9)

where 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 represents the level of total vibration.

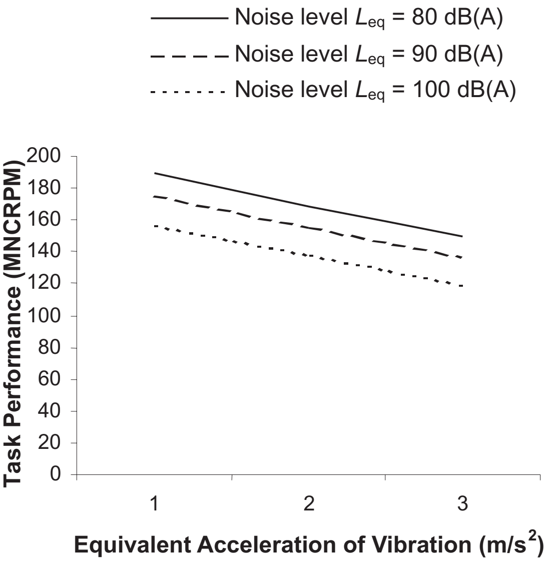

Figure 6. Relationship between task performance and equivalent acceleration of vibration at different noise levels for both male and female operators. *Notes.* MNCRPM—mean number of characters read per minute.

4. DISCUSSION

The hypotheses listed in section 1 were tested using ANOVA and it was found that the first five hypotheses were valid whereas the last two were not. The findings of the present work are supported by many studies. Taylor, Melloy and Dharwada [13] found that random and intermittent noise had negative effects on the accuracy of an easy search task performed by both males and females subjects. Bengtsson, Persson Waye and Kjellberg [14] found that low frequency noise adversely influenced the performance of female subjects on two tasks sensitive to reduced attention and on a proof reading task. Low frequency noise annoyed male operators and should be considered in occupational exposure assessment [15]. Low frequency noise at 50 dB(A) could be perceived as annoying and adversely affecting mental performance (concentration and visual perception) of male operators [16]. Men's and women's performance decreased in spatial ability tasks as well as in tasks related to motion sickness [17]. It was also found that noise impaired performance in focused-attention kinds of tasks [4].

The results also indicated that vibration played a dominant role in decreasing the operator's performance of a readability task on a laptop screen in a mobile driving environment. Guedry, Benson and Moore [18] found that whole-body angular oscillation of 2.5 Hz (± 20° peak velocity) degraded a visual search task, but did not produce signs or symptoms of motion sickness within a 5-min exposure.

Sherwood and Griffin [19] suggested that vibration disrupted central cognitive mechanisms utilized during the processing of information in short-term memory. Kato and Hanai [20] showed that sensitivity at 20 and 40 Hz on inclined rigid backrests (inclined at 20° and 40° from the vertical) was significant and about 1.4 to 1.5 times greater than on a vertical backrest but there was no significant difference between the two contours for inclined backrest. Village, Morrison and Leong [21] also reported performance impairment due to multiple vibration frequencies. Further, Wells and Griffin [22] indicated a relationship between biodynamic behaviour and visual performance during vibration.

Since the interaction between the subject's gender and noise was statistically significant, simple main effect analysis showed that both males and females were affected by noise and their task performance decreased. The literature review showed that very few studies were conducted in the past. Baker and Holding [23] found interactions of the subject's gender, time of day, and type of noise for tasks that placed a heavy demand on short-term working memory.

At the same time interaction between gender and vibration was also found to be statistically significant. This finding is supported by Griffin and Hayward [24], who found that the reading speed of male and female subjects was reduced significantly at frequencies between 1.25 and 6.3 Hz, with greater impairment at higher magnitudes of vibration. Maximum interference with reading was reported at 4 Hz. Corbridge and Griffin [25] reported that the letter writing speed of male and female passengers decreased and subjective ratings of writing difficulty increased with increasing vibration magnitude, particularly in the frequency range of 4 to 8 Hz. Writing difficulty also increased with an increasing duration of vibration. Exposure of 10 s to vibration of 5 Hz at 2 m/s^2 rms makes a writing task extremely difficult.

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 [26], who also reported that relatively short exposures to noise and vibration typical of those levels that are found in industrial vehicles do not significantly affect performance in cognitive tasks nor saliva cortisol levels even if work in these environments can be experienced as more difficult or stressful. The finding is also supported by Sandover and Champion [27], who observed that the combined effect of noise and vibration did not affect the subjects' performance in mental arithmetic tasks.

5. CONCLUSIONS

On the basis of the results of this study as discussed in section 4, the following conclusions were drawn.

- Noise has a significant negative effect on the performance of a readability task in a mobile driving environment.
- Vehicular vibration has a significant negative effect on the performance of a readability task of an operator in a mobile driving environment.
- Organismic variable gender has a significant negative effect on the performance of a readability task in a mobile driving environment.
- The interaction between gender and noise as well as gender and vibration are statistically significant.
- The combined effect of noise and vibration do not produce a significant effect on computer operators' performance of a readability task.
- The interaction between gender, noise, and vibration was found to be statistically insignificant for the readability kind of task considered in this study.

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