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Investigating Data Entry Task Performance on a Laptop Under the Impact of Vibration: The Effect of Color

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The last 20 years have seen a tremendous growth in mobile computing and wireless communications and services. An experimental study was conducted to explore the effect of text/background color on a laptop computing system along with variable environmental vibration on operators' data entry task performance in moving automobiles. The operators' performance was measured in terms of the number of characters entered per minute without spaces (NCEPMWS) on a laptop computing system. The subjects were divided into 3 categories, namely, Novices, Intermediates and Experts. Findings suggest a re-evaluation of existing laptop designs taking ergonomics into consideration. It appears that proper selection of text/background color on the laptop coupled with controlled vehicular speed could result in a better quality of interaction between human and laptops and it could also resolve the problem of poor data entry task performance.

driving environment   vibration   text/background color   novice   intermediate   expert

1. INTRODUCTION

With the rapidly increasing pace of computerization in almost every aspect of life, the use of visual display units (VDUs) has been continually on the rise. A survey on the U.S. mobile industry found that mobile device sales grew by 40% between 2002 and 2003 and predicted that PDA (personal digital assistant)/mobile phone sales would outstrip the sale of personal computers by 2005 with the majority of companies switching to wireless networks by 2008 [1]. Numerous reports have observed that computer usage causes occupational problems and discomfort to user's eyes [2]. Rehn, Lundström, Nilsson, et al. [3] found that whole-body vibration (WBV) exposure causes health problems, e.g., lumbago. Developments in information system design suggest that VDUs will continue to be used as a medium for presentation of a large amount of connected text as observed in videotext, electronic journals, dynamic books and similar applications. In addition the recently emerging WAP (Wireless Application Protocol)-based technological systems like laptops, palmtops, etc., are expected to be a commonplace entity in mobile human–computer interaction (HCI) environments of tomorrow. Such systems will be widely used by executives while commuting, by security staff, police, tourists, etc., so the users' performance needs to be evaluated ergonomically in the mobile environment of HCI. When users perform tasks in a mobile setting, the task and the environment compete for the user's attention [4]. Therefore, the actual usage of information or services in mobile computing is restricted by a number of constraints.

Griffin and Lewis [5] have reported reading difficulty with an increase in WBV. WBV has been found to have acute detrimental effects on visual acuity equilibrium and manual dexterity, and it has caused muscular fatigue [6]. Lewis and Griffin [7] have also shown that seat-to-head

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vibration has an affect on human performance. The frequencies which affect motor performance lie between 4 and 5 Hz with a decrement in performance progressively smaller at higher or lower frequencies [8]. Chronic health effects were also reported with WBV (e.g., [9]). Long exposures to vibration were found to be responsible for back injuries and digestive and circulatory disorders. Off-desktop computing, like mobile computing on a laptop or similar devices, is related to numerous user interface challenges. Some will be surprisingly hard to solve. Data entry is a computer-related task extensively performed by operators both in mobile and stationary HCI environments. Data entry includes writing e-mails and chat messages, filling forms, typing commands, taking notes, authoring articles, coding programs, etc. The need to enter text off the desktop has driven numerous inventions in text entry in recent years, although the majority has not been properly researched, with either theoretical or empirical human performance studies. There have also been more comprehensive reviews of novel text input methods [10, 11, 12, 13].

Rempel, Honan, Serina, et al. [14] stated that over 50% of occupational injuries were strain injuries from an overuse of hands. Analyses of cumulative trauma injury (CTI) emphasize that unnatural postures and repetitive movements are the main contributing factors in occupational injuries. Sauter, Schleifer and Knutson [15] reported data entry tasks and their musculoskeletal effects on several hundred VDU users. Aspects of worker posture and workstation design were objectively assessed for VDU users. Multiple regression analysis was used to examine the relationship between ergonomic variables and musculoskeletal discomfort. The results showed a strong relation between them. Czaja and Sharita [16] investigated age differences in the performance of a computer data entry task and the extent to which these differences remained the same as task experience increased. The results indicated that older people completed significantly less work than middle-aged and younger people.

Text/background color of display is a variable that has been found to have a detrimental effect on the performance of the user population specially for desktop and laptop types of computing system. Ling and Schaik [17] proposed design guidelines for the use of color on the web by experimenting with different color combinations for the presentation of information on navigation bars. They studied the effect of the combination of text/background color on visual search performance and subjective preference. The analysis showed that higher contrast between text and background color led to faster searching and was rated more favorably. Color can also be an effective way of communication if chosen properly. Different color combinations are used in advertisements and similar kind of tasks. Advertisers aim at presenting information in an attractive way by choosing different color combinations without being aware of the importance of a proper selection of color combination for such information.

Wang and Chen [18] reported that text/background color combinations had a significant effect on reading performance. The authors investigated the effect of text/background color combinations which were white-on-black, black-on-white, blue-on-white, red-on-white, blue-on-yellow and green-on-white. Analyses of variance (ANOVAs) showed that different color combination settings of the display had a significant effect on reading performance. This paper suggested a greater difference in color between text and background to maintain good reading performance. The critical factor in text/background color combinations is luminance contrast between the text and background colors. Shieh and Lin [19] indicated that visual preference increased as the luminance contrast of text/background color combinations became greater. Similarly, Wang, Chen and Chen [20] reported that subjects' searching performance on a "leading display" improved when the color difference of text/background became larger. (Leading display is a conventional Internet homepage design method for presenting dynamic information on visual display terminals).

A survey of the literature has revealed that computer task-related capabilities of operators have not been studied in a major way under the impact of vibration and text/background color on laptops. As user populations of the future are likely to be more mobile than today's, this kind of study becomes more important. There are various factors that can influence data entry but lack of resources and constraints in controlling other factor that might affect the result prevent one from considering a large number of factors together.

The pace of research in the field of exposure to transportation vibration, specifically in computer-related tasks, has been rather slow in comparison to the growing increase in the use of automobiles. Therefore the present study was designed to explore how the users' ability is affected in terms of their performance of data entry while working on a laptop under the impact of varying levels of vibration and text/background color on laptops in a mobile setting.

2. METHOD

2.1. Subjects

One of the important requirements for performing the experiment was the selection of an appropriate type of subjects. Thirty subjects (20 males and 10 females) participated in this study. The spread of the subjects was not arbitrary and aimed at providing the greatest scope for drawing conclusions and making findings. Mean height, weight and the age of each group of subjects who participated in the different experimental investigations are presented in Table 1. All the subjects had normal vision either with or without glasses. None of them had any previous history of neuromuscular disorders. The subjects had almost the same educational qualification. They were divided into three groups, namely, Novices, Intermediates and Experts. Each group comprised 10 subjects. The groupings were based on the experience of working on laptops in a mobile setting:

- Novices had rarely or never done mobile computing;
- Intermediates performed mobile computing tasks at least twice a week;
- Experts performed mobile computing not less than five times per week.

It was clear in the conceptual stage of the experiment that finding subjects willing to do the experiment who had very rarely used a laptop in a mobile setting would be extremely difficult. At the start of the testing session, each participant was given standard information explaining the study's purpose and procedures and was asked to sign an informed consent form. This study was approved by the human ethics committee of Universiti Sains Malaysia.

TABLE 1. Mean and Standard Deviation of Age, Height and Weight of the Subjects

	Age (years)		Height (m)		Weight (kg)	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Novices	23.3	2.73	1.68	0.0656	65.5	6.32
Intermediates	25.8	3.89	1.77	0.0712	75.2	5.32
Experts	28.8	4.82	1.67	0.0519	70.8	7.32

2.2. Stimuli and Experimental Task

A laptop (Armada 1500, Compaq, USA) was employed in all the experiments. The sensor of the vibration level meter was kept on a specially designed platform which did not affect the impact of vibration and the display was kept in front of the experimenter to constantly monitor the level of vibration.

The mean value of the angle between eye-sight level and the centre of the screen of the laptop for all the subjects remained at approximately 15 ± 3.16 °C. The temperature of the vehicle was maintained at approximately 26 ± 3 °C. While performing the experimental task the level of vibration in the mobile environment was kept at a prespecified value by constantly monitoring the level of vibration in the x, y and z directions and running the vehicle at the desired speed.

Before the actual experiment a trial session was arranged in the test vehicle. This was done mainly for two purposes. The first object of this trial session was to familiarize the subjects with the experimental procedure; the second one was to know the subjects' reactions in connection with the recorded text input in the audio cassette that was played during the experimental session.

The subjects were not comfortable with this style of the presentation of the stimuli; therefore one experimenter sat by the side of the subject to read the text to be entered. Out of 30 subjects 19 preferred this style of stimuli presentation but requested slow-speed reading so that the text entry task could be completed without difficulty. All subjects in each group refreshed prior to the experiments. They were required to sit in the vehicle seat (without a back rest) with the two hands on the keyboard (as was observed to be the users' practice) while working on VDUs (Figure 1). As far as the zero level vibration condition was concerned, the data entry task performance was measured before running the test vehicle. Before performing the experimental task in a mobile setting the subjects sat in the vehicle at a prespecified level of vibration for 60 min and then the stimulus was presented to them. After completion of the text entry task that continued for 10 min for each level of vibration separately, the content entered was saved with the name of the subject. It was downloaded later to check for errors. The experimental procedure was repeated separately for 0.85 and 1.65 m/s^2 vibration levels. The interstimulus duration was kept at 30 min and during this period the subjects were isolated from the driving environment. Two text/background color employed in this experiment were black characters on white background and white characters on black background. The experimental task was repeated for both text/background color combinations. The experimental tasks presented to the subjects were randomized during the experimental sessions. Human performance in terms of the number of characters entered per minute without spaces (NCEPMWS) was recorded at approximately the same time of the day on each day of the experiment. This was done so as to avoid any temporal effect in experimentation that might have its impact on the subjects' performance.

(a) (b)

Figure 1. Operators performing a data entry task on a laptop.

2.3. Experimental Setup

Experimental investigations were carried out in a real-life driving environment in a passenger car (Waja, Malaysia). This particular type of car was chosen because around 65% of people use this car. Most users of laptops in a mobile setting were also found to be using this particular car. Following are the vehicle's important specifications: engine: S4PH 4-cylinder 16-valve DOHC, maximum power: 82 kW @ 6000 rpm; maximum torque: 148 Nm @ 4000 rpm; fuel system: multi-point fuel injection; bore and stroke: 76 × 88 mm; displacement: 1597 cc; front suspension: MacPherson strut with a stabilizer bar; rear suspension: multilink with a stabilizer

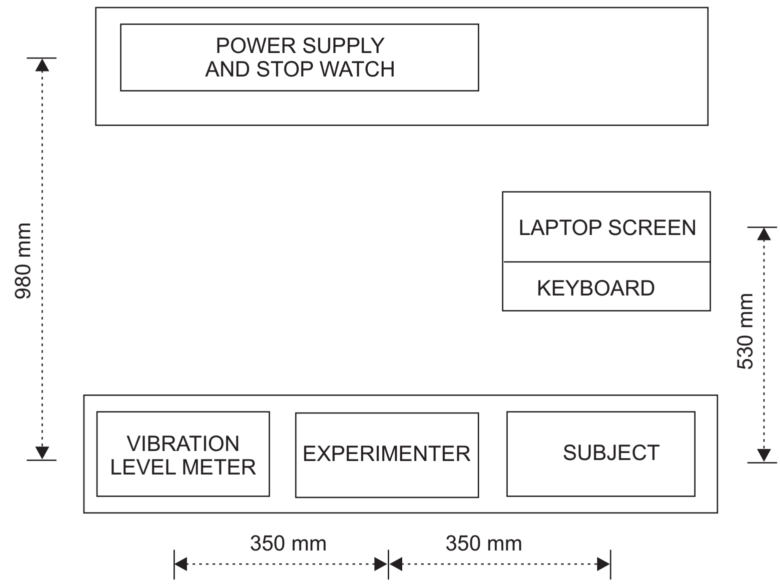

Figure 2. Schematic diagram of the experimental setup without vibration (zero level) and with vibration levels of 0.85 and 1.65 m/s^2 in a human–computer interaction environment.

bar; maximum speed: 190 km/hr; overall length: 4465 mm; overall width: 1740 mm; overall height: 1420 mm; wheelbase: 2600 mm.

The setup comprised the following subsystems: (a) vibration level meter (Deltatron 4504, Bruel & Kjær, Denmark); (b) a 12-volt battery for an energizing amplifier (type 2260, Bruel & Kjær); (c) laptop (Armada 1500, Compaq, USA); (d) pieces of connecting wires, a battery charger, distilled water; etc. (Figure 2).

2.4. Error and Error Handling

Another important dimension to consider in such experiments is error rate. What matters is the effective speed, or speed after correction. Experimentally there are different ways of handling errors in studies; each has different implications for the results of a text input study. Some leave errors in the text and report them separately [21]. Others do not allow errors, e.g., the testing program will not proceed until the correct character is entered [22]. Yet others require the participants to correct their errors, and measure their effective speed including errors. The amount of time needed to correct errors depends on the design of the error correction mechanism; hence there are no set rules to trade off errors with speed. Typing accuracy is defined as the percentage of characters correctly typed [23]. In a typing task the general rule for error handling is based on reviewing the entered text and then comparing it to the given text with time being the measured variable. Error was also counted in this experiment to see that it did not exceed a value of ±5% to be acceptable. In this experiment error was counted on the basis of characters typed correctly, e.g., the given text was "Please come to meet me at the play ground where match will be played." The text entered was "Pleose come to meet me at the plat ground where match will be played."

The sentence has 55 characters without spaces; the entered text has two mistakes: one in "Please", the other in "play". Therefore the error is (2/55) × 100 = 3.63% and typing accuracy is (100 – 3.63) = 96.37%. Typing speed is reported in this study as NCEPMWS.

2.5. Measurement of Vibration

The ISO 2631-5:2004 standard [24] was consulted when measuring vibration and according to its recommendation the evaluation procedure of ISO 2631-1:1997 [25] was adopted. A Deltatron 4504 tri-axial accelerometer from Bruel & Kjær (Denmark) was mounted on the test vehicle seat to register the level of vibration.

The measuring range for that accelerometer was 0.10 – 7 500 m/s^2. The frequency range in which this instrument could work was 1–1 000 Hz. This instrument could make simultaneous 3-channel measurements in the *x*, *y* and *z* directions. The levels of vibration were measured with respect to the standard biodynamic co-ordinate system [25]. The vibration level meter was calibrated in the *x*, *y* and *z* directions prior to measurements. 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 rms value. The peak is 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 the standard's recommendations, for vibration with crest factors below or equivalent to 9, the basic evaluation method is normally sufficient. The accelerometer was connected to the WBV front end (type 2693, Bruel & Kjær) and this was connected to the modular sound level meter which in this case was used for data collection and display (type 2260, Bruel & Kjær) and later downloaded to a personal computer for further analysis. Total equivalent vibration was calculated as per the recommendations of ISO 2631-1:1997. The vibration levels were measured with respect to the standard biodynamic co-ordinate system (Figure 3). An equivalent vibration level means the power average of the amount of vibration measured in a specific period of time; it has been derived from the equivalent noise level of the sound level meter.

$$\text{Total equivalent vibration} = [(1.4\, a_{wx})^2 + (1.4\, a_{wy})^2 + (a_{wz})^2]^{1/2},$$

where a_{wx}, a_{wy} and a_{wz} are the weighted rms acceleration values in the *x*, *y* and *z* directions and the factor 1.4 is the ratio of the longitudinal to the transverse acceleration limits for the frequency range in which humans are sensitive. It was found that total vibration varied from 0.30 to 1.75 m/s^2 (Table 2); whereas the vibration range for the present study was set at 0, 0.85 and 1.65 m/s^2. Zero level of vibration means a vehicle was not moving at all. This level was necessary to know the baseline value of the subjects in terms of NCEPMWS.

TABLE 2. Vehicular Vibration at Different Speeds

Speed (km/hr)	20	40	60	80	100	120
Vibration (m/s^2)	0.30	0.75	1.25	1.59	1.70	1.75

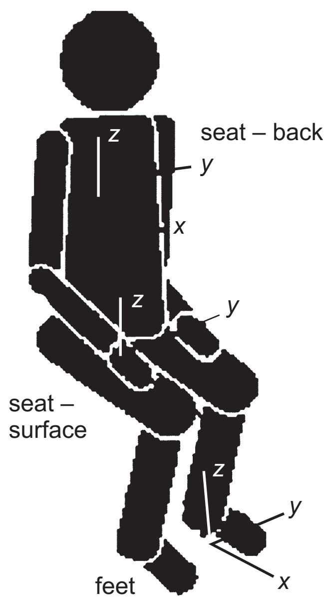

Figure 3. Whole-body vibration biodynamic co-ordinate system for a seated subject.

3. RESULTS

Three experiments were conducted to study the effect of experience on the performance of a data entry task. A preliminary test conducted on the ANOVA model through Bartlett's test [26] indicated that the observed chi-square value was higher than the tabulated value at $\alpha = .05$. This implied that the within-subjects interaction could not be dropped from the ANOVA model.

3.1. Experiment 1

In this experiment, Novices were tested for the performance of a data entry task under varying levels of vibration and text/background color combinations.

The result of ANOVA summarized in Table 3 implies that the effect of vibration and text/background color combinations was statistically significant. Also the interaction between vibration and text/background emerged as statistically significant.

TABLE 3. Summary of the Analysis of Variance (ANOVA) Pertaining to Studies of Vibration Effects When Novice Operators Performed a Data Entry Task Under Various Text/ Background Color Combinations

Source of Variation	*SS*	*df*	*MS*	*F*
Between-Subjects	—	9	—	—
Within-Subjects	—	50	—	—
A (Vibration)	1015.19	2	507.59	8.32*
A × Subjects (error I)	1097.64	18	60.98	—
B (Text/ background color)	686.72	1	686.72	10.94*
B × Subjects (error II)	564.75	9	62.75	—
A × B	660.20	2	330.10	6.02*
A × B × Subjects (error III)	986.58	18	54.81	—

Notes. $^*p < .05$.

The significant interaction between the vehicular vibration level and the text/background color combinations necessitated an analysis of the simple main effects. Its result (Table 4) indicated that level of vibration was statistically significant at two levels of vibration only (0.85 and 1.65 m/s^2) when interacting with text/background color combinations for Novices in a real driving environment. However, the same was not true in the case of vibration level under the varying levels of text/background color combinations, i.e., black characters on a white background and white characters on a black background.

TABLE 4. Analysis of Simple Main Effects When Novice Operators Performed a Data Entry Task at Various Text/Background Color Combinations and Varying Levels of Equivalent Vehicular Vibration

Source of Variation	*SS*	*df*	*MS*	*F*
B (Text/background color combination) at				
Vibration level 1	26.70	1	26.70	0.97
Vibration level 2	138.20	1	138.20	5.02*
Vibration level 3	168.48	1	168.48	6.12*
B × Subjects (error)	495.54	18	27.53	—
A (Vibration Level) at				
B1 (white characters on black background)	35.42	2	17.71	0.87
B2 (black characters on white background)	81.84	2	40.92	2.01
A × Subjects (error)	366.48	18	20.36	—

Notes. $^*p < .05$.

The mathematical relationship between NCEPMWS for varying levels of vibration under the influence of a particular text/background color combinations was explored for Novices and the following model was obtained:

$$(CE)_{B1} = 50.86 - 5.01\,V, \qquad (1)$$

$$(CE)_{B2} = 68.72 - 8.24\,V, \qquad (2)$$

where $(CE)_{B1}$ and $(CE)_{B2}$ represent NCEPMWS for text/background color combinations B1 and B2 respectively (B1—black characters on white background, B2—white characters on black background) and V is the value of vibration considered in this study (0, 0.85 and 1.65 m/s^2). Figure 4 compares the performance of Novice operators for varying levels of equivalent vehicular vibration for different text/background color combinations.

3.2. Experiment 2

In this experiment, the Intermediate group of subjects was tested for the performance of a data entry task under varying levels of vibration and text/background color combinations.

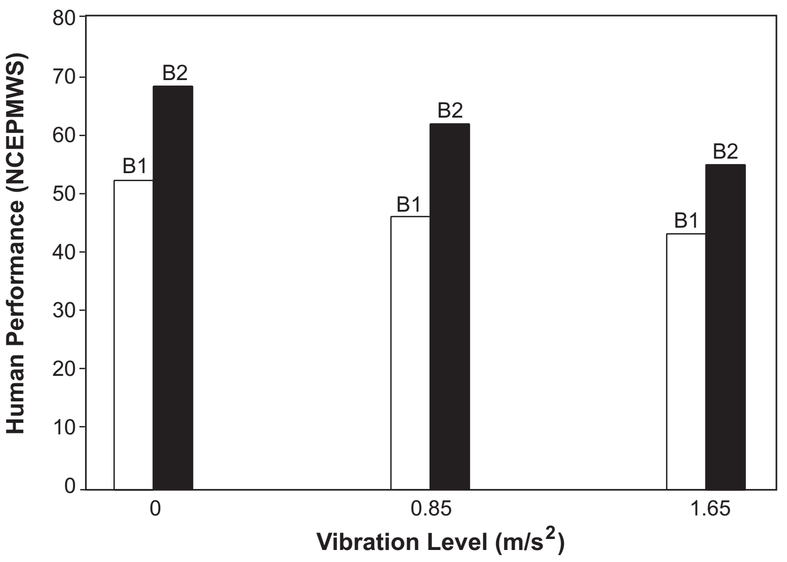

Figure 4. Comparison of operators' performance (in number of characters entered per minute without spaces, NCEPMWS) for varying levels of vibration and text/background color combination for Novices. *Notes.* B1—black characters on white background, B2—white characters on black background.

TABLE 5. Summary of the Analysis of Variance (ANOVA) Pertaining to Studies of Vibration Effects When Intermediate Operators Performed a Data Entry Task Under Various Text/Background Color Combinations

Source of Variation	*SS*	*df*	*MS*	*F*
Between-Subjects	—	9	—	—
Within-Subjects	—	50	—	—
A (vibration)	1165.74	2	582.87	9.32*
A × Subjects (error I)	1125.72	18	62.54	—
B (text/ background color)	471.93	1	471.93	8.12*
B × Subjects (error II)	523.08	9	58.12	—
A × B	777.16	2	388.58	7.18*
A × B × Subjects (error III)	974.16	18	54.12	—

Notes. *$p < .05$.

The result of ANOVA summarized in Table 5 implied that the effect of vibration and text/background color combinations was statistically significant. Also the interaction between the vibration and text/background emerged as statistically significant.

The significant interaction between the vehicular vibration level and the text/background color combinations necessitated an analysis of the simple main effects. Its result (Table 6) indicated that the level of vibration was statistically significant at only one level of vibration (1.65 m/s^2) when interacting with text/background color combinations for Intermediate subjects in a real driving environment. However, the same was not true in the case of vibration levels under the varying levels of text/background color combinations, i.e., black characters on a white background and vice versa.

TABLE 6. Analysis of Simple Main Effects When Intermediate Operators Performed a Data Entry Task at Various Text/Background Color Combinations and Varying Levels of Vehicular Vibration

Source of Variation	*SS*	*df*	*MS*	*F*
B (text/background color combination) at				
Vibration level 1	30.18	1	30.18	1.24
Vibration level 2	87.13	1	87.13	3.58*
Vibration level 3	300.84	1	300.84	12.36*
B × Subjects (error)	438.12	18	24.34	—
A (vibration level) at				
B1 (white characters on black background)	82.66	2	41.33	1.89
B2 (black characters on white background)	71.73	2	35.86	1.64
A × Subjects (error)	393.66	18	21.87	—

Notes. *$p < .05$.

The mathematical relationship between NCEPMWS for varying levels of equivalent vibration under the influence of a particular text/

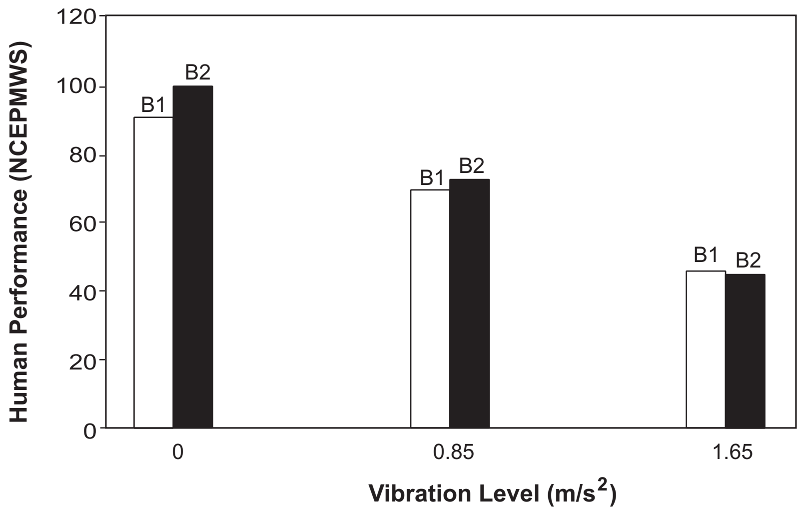

Figure 5. Comparison of operators' performance (in number of characters entered per minute without spaces, NCEPMWS) for varying levels of vibration and text/background color combination for Intermediates. *Notes*. B1—black characters on white background, B2—white characters on black background.

background color combination was explored for Intermediates and the following model was obtained:

$$(CE)_{B1} = 89.72 - 25.24\,V, \tag{3}$$

$$(CE)_{B2} = 98.86 - 30.81\,V, \tag{4}$$

where $(CE)_{B1}$ and $(CE)_{B2}$ represent NCEPMWS for text/background color combinations B1 and B2 respectively (B1—black characters on white background, B2—white characters on black background) and V is the value of equivalent vibration considered in this study (0, 0.85 and 1.65 m/s^2). Figure 5 shows the performance of Intermediate operators for varying levels of equivalent vehicular vibration for different text/background color combinations.

3.3. Experiment 3

In this experiment, the Expert group of subjects was tested for the performance of a data entry task under varying levels of vibration and text/background color combinations. The result of ANOVA summarized in Table 7 implied that the effect of vibration was statistically significant while text/background color was found to be statistically nonsignificant. Interaction between vibration and text/background color was found to be statistically significant.

TABLE 7. Summary of the Analysis of Variance (ANOVA) Pertaining to Studies of Vibration Effects When Expert Operators Performed a Data Entry Task Under Various Text/Background Color Combinations

Source of Variation	*SS*	*df*	*MS*	*F*
Between-Subjects	—	9	—	—
Within-Subjects	—	50	—	—
A (Vibration)	2006.78	2	1003.39	15.27*
A × Subjects (error I)	1182.78	18	65.71	—
B (text/background color)	64.45	1	64.45	1.24
B × Subjects (error II)	467.82	9	51.98	—
A × B	1115.12	2	557.56	10.98*
A × B × Subjects (error III)	914.04	18	50.78	—

Notes. **p* < .05.

The significant interaction between the vehicular vibration level and the text/background color combinations necessitated an analysis of the simple main effects. Its result (Table 8) indicated that the level of vibration was statistically significant at two levels of vibration only (0.85 and 1.65 m/s^2) when interacting with text/background color combinations. However, the same was not true in the case of vibration level under varying levels of text/background color combinations, i.e., black characters on white

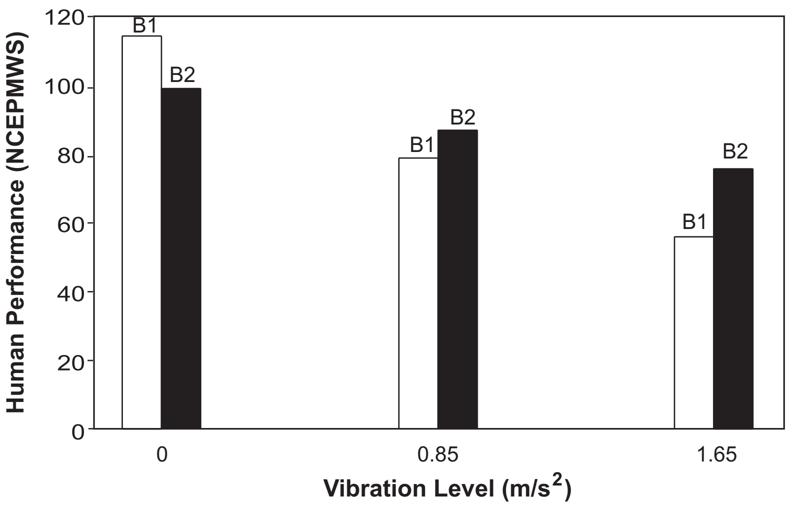

Figure 6. Comparison of operators' performance (in number of characters entered per minute without spaces, NCEPMWS) for varying levels of vibration and text/background color combination for Experts. *Notes*. B1—black characters on white background, B2—white characters on black background.

background and vice versa. The mathematical relationship between NCEPMWS for varying levels of vibration under the influence of a particular text/background color combination was explored for the Expert group of operators and the following model was obtained:

$$(CE)_{B1} = 103.82 - 30.24\ V, \quad (5)$$

$$(CE)_{B2} = 98.27 - 14.54\ V, \quad (6)$$

where the symbols have their usual meaning. Figure 6 shows the performance of Expert operators for varying levels of vehicular vibration for different text/background color combinations.

TABLE 8. Analysis of Simple Main Effects When Expert Operators Performed a Data Entry Task at Various Text/Background Color Combinations and Varying Levels of Vehicular Vibration

Source of Variation	*SS*	*df*	*MS*	*F*
B (text/background color combination) at				
Vibration level 1	91.76	1	91.76	2.64
Vibration level 2	683.03	1	683.03	19.65*
Vibration level 3	408.77	1	408.77	11.76*
B × Subjects (error)	625.68	18	34.76	—
A (vibration level) at				
B1 (white characters on black background)	167.12	2	83.56	3.23
B2 (black characters on white background)	63.12	2	31.56	1.22
A × Subjects (error)	465.66	18	25.87	—

Notes. $^*p < .05$.

4. DISCUSSION

The studies that had been carried out provided important guidelines for future system designers and it is hoped that they will further stimulate ergonomists' curiosity regarding new ergonomic designs that would ease the operation of systems during data entry. Studies 1–3 were based on the independent variables of vibration and text/background color on the laptop. Both of the independent variables significantly affected the performance of Novices and Intermediates. On the other hand the vibration variable was significant for the Expert group too, while text/background color was found to be statistically nonsignificant. Besides when the interactive effects of those independent variables were evaluated, it was found that the interaction of vibration with text/background color was statistically significant for all groups of subjects who participated in this study. As expected, it was found that when operators worked in a vibratory HCI environment, their performance deteriorated. Further it was found that text/background color on laptops also affected the operators' performance. When the interaction of those variables was evaluated it was found that the interaction of vibration with text/background color on laptops was significant for all three studies. Those studies revealed that operators' performance was affected irrespective of their experience of working in a mobile setting on a laptop.

Thus, the conclusion is that vibration-induced stress results in deteriorated work performance in a mobile HCI environment. Text/background color on laptops is also an important variable that should be chosen cautiously in order to improve operators' performance in the context of a mobile HCI environment. The present study also revealed better data entry task performance in the case of white characters on a black background as compared to black characters on a white background. It seems that reduced operational load resulting in better data entry task performance may be due to the fact that a black background is less glare-prone in a mobile HCI environment. It appears that very few studies are available in literature pertaining to the theme under discussion so that the present results could be discussed in light of other studies. One finding in the present study is that vibration has significant bearing on operators' performance of data entry. Other studies report the influence of vibration on readability tasks but the effect on the performance of a data entry task has not been explored. Ishitake, Ando, Miyazaki, et al. [27] found that the disturbances of visual performance were dependent on the vibration frequency with a maximum reduction of visual acuity at a frequency of 12.5 Hz. Griefahn, Bröde and Jaschinski [28] revealed that participants in the 19–26 years age range 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-axis (vertical and lateral) whole-body vibration. The fore-and-aft, lateral and vertical forces on a seat and a backrest have been investigated at frequency range of 0.25–10 Hz at four vibration magnitudes (0.125, 0.25, 0.625 and 1.25 m/s^2) and the result indicated that forces on the seat depended on whether the feet were supported on a foot rest or not [29].

Another major finding of the present work is that the text/background color combination has significant bearing on operators' performance of data entry. That finding is supported by Wang et al.'s study [20] who reported that subjects' searching performance on a leading display improved when the color difference of text/background became large. Also Shieh and Lin [19] indicated that visual identification performance and subjective preferences increased as the luminance contrast of text/background color became greater. On the other hand Wang and Chen [18] found that the interaction between jump length and color combination of a leading display also had a significant effect on subjects' reading performance. One weakness of the present study is lack of participants' feedback related to side effects, e.g., neck and shoulder pain, ophthalmic problems, back injuries, etc. On the basis of the results of this research it can be recommended for operators of laptops to use a black background while maintaining white for characters when performing data entry tasks in a mobile setting. Besides this vehicle speed should be controlled to minimize vibration. The optimum vehicular speed will depend mainly on road conditions and the type of suspension system used in the automobiles. Perhaps proper selection of text/background color coupled with controlled vehicle speed will result in better performance of data entry. Also interior design features of automobiles can provide fixtures for proper placement of laptops with cushion pads, resulting in a reduced vibratory effect.

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