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Ocular Movement Analysis during Reading on two media types and under the effect of Whole Body Vibration

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Abstract. *This paper presents the ocular movement analysis when reading texts on Tablet or printed paper under the influence of Whole Body Vibration (WBV). Such situations are very common nowadays, since the population spends more time travelling from home to work/study and wants to optimize their time doing activities such as reading. Every means of transport produces WBV. Mobile technologies (Tablets, Smartphones, etc) also make part of the modern lifestyle. However, there are no much study trying to understand such interactions (WBV and media) and the research presented here is the kick off analysis on that direction. For that, thirty university students (twelve females and eighteen males) took part in an experiment undertaken in laboratory condition. The whole body vibration was applied in the z-axys, at 5 Hz and 0.8 m/s*^{2} *rms amplitude. The results show that for these test parameters, reading on Tablet under the influence of WBV was the best situation. On the contrary, reading on paper with no WBV was the worst.*

1. INTRODUCTION

Whole body Vibration (WBV) is very present on the daily life of people. Every means of transport produces vibrations that are transmitted to the body as a whole. The vibration characteristics from one type of transport to the other are different mainly in terms of excitation direction, amplitudes and frequencies. The performances of tasks are affected by these characteristics, the duration of the activity and the characteristics of the activity (Griffin, 1996).

Studies are found in the literature investigating the influence of WBV on reading (Griffin, et al., 1994), (Griffin, 1996), (Hancock, et al., 2008), Mansfield et al (2005). The majority of that uses subjective parameters (such as the degree of difficulty), or objective parameter (such as the time to perform the reading) as the analysis parameters. From the best of our knowledge, only the studies made by the Group of Acoustics and Vibration in Human Beings (GRAVI$_{SH}$) of UFMG used the ocular movement of the eye to evaluate such influence (Duarte, et al., 2009), (Duarte, et al., 2010b), (Duarte, et al., 2010a), (Duarte, et al., 2010), (Duarte, et al., 2010).

Since Tablet is a new technology, no studies were found correlating the influence of WBV and media type on reading as presented here. There are studies performed on reading newspaper (Bhiwapurkar, et al., 2011) or normal paper reading (Hancock, et al., 2008), (Sundstrom, et al., 2008) only.

The universal use of mobile devices that allow data, sound, images and text to be transferred to different digital forms, such as electronic media, has increased the amount of reading information (or other visual tasks) by people of both genders and different ages. Moreover, great attention is given to E-papers ("electronic paper") because of its low weight, low power consumption and readability in sunlight (Sanders (1993) *apud* Yu-Ting Lin (2009)). This was the motivation for this research aimed to evaluate the influence of WBV on eye movements during reading performed on two different media types (tablet and printed paper).

Reading is a very complex visuomotor activity that requires a coordinated eye movement. When performed under mechanical vibration, it may be associated with changes of the image on the retina and degradation of visual function, which can impact on health, comfort and task performance (Griffin, 1996). The readability of a text depends on the time that the image remains on the eye's fovea retina, so that the reading and understanding of alphanumeric characters can be impaired under vibratory movements.

WBV has a direct relation with the reading difficulty, being that a function of the acceleration amplitude and frequency, as well as the context, and causes major nonlinear effects in the human body (Griffin, 1996).

To read materials on newspapers, books or electronic media, hands hold, and under the influence of mechanical vibration, can produce a combination of head and hands movement that usually is associated with visual impairments that occur at low frequency vibration (Ore, 1986 *apud* Griffin, 1996).

WBV causes the translational displacement of the reading material to be greater than the angular displacement of the eyes. However, this is usually compensated by the rotational movement of the head, through the vestibular-ocular reflex (VOR), which stabilizes the image of an object on the retina. Hands displacements are greater between 2-5 Hz, and at these frequencies, the reading difficulty is probably the highest (Hayward and Griffin, 1989 *apud* Griffin, 1996).

Griffin (1996) states that for a seated person, the image motion on the retina may result from the vertical and lateral vibration displacement of the display. This is equivalent to the rotational eye movement in the Y or Z axis. Differences between the vertical and horizontal movement effects on the retina may occur due to the asymmetric shape of the visual detail or because the image is more likely to overlap toward the other. This can cause a partial or total visual impairment, according to the complexity of the visual task.

While reading, the eyes fixate the majority of the words on a text and 15% of them are re-fixated. Many words are skipped and 2-3 letters of the words only receive fixation 25% of the time. It is noted that, on average, during reading, one eye fixation lasts about 200-250 ms and it is followed by 7-9 (approximately 2-3º) saccades characters forward. From these, 10-15% of the saccades are regressive. Towards the end of the line, a large oblique saccade is made slightly by the eyes from the right to the left near the beginning of the next line. The size of this return depends on the length of the line (50 characters, approximately 17º) according to Rayner (1998).

Other authors such as I-Hsuan, Shen et al (2009) evaluated the effects of media display on performance and visual fatigue, in addition to the font style and polarity, and concluded that the media did not show significant effect on reading speed. On the other hand, the conventional paper provides greater visual comfort than electronic media, although both have similar performance in visual search task (Jeng et al (2005) *apud* Shen (2009)). However, the above studies are related to reading on a static environment, what makes them subject of future studies under vibration.

So, the objective of the present work is to understand the influence of WBV on reading, comparing Tablet with conventional paper, by using the ocular movement as the analysis parameter.

2. SETUP AND INSTRUMENTATION USED

Figure 1 shows a schematic view of the setup used for the tests presented here, with a photo of such configuration presented in Figure 2. The vibrating platform consisted of a steel plate (700 x 1000 x 3 mm and folded edges), supported by four 1020 steel compression springs (76 mm external diameter, 350 mm height, 6 mm wire diameter and 9 coils). PVC tubes positioned outside a steel tube welded into a flat metal basis were used to guide the springs. That assembly was used to ensure the vertical motion of the spring, reducing fluctuations in the x- and y- axes. Therefore, the main excitation was in the z-axis, as this is the direction of greatest interest for this study.

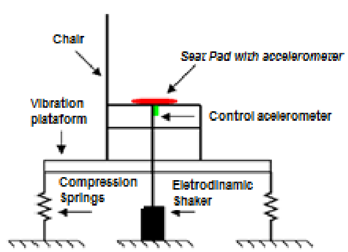

Figure 1: Schematic drawing of the WBV setup and instrumentation.

Figure 2: Photo of the setup used for the WBV Reading Tests.

A Dynamics Solution shaker, VTS150 model, was installed under the plate. A steel cable was used to transmit the excitation from the shaker to the platform. This cable was fixed on the volunteers' chair as shown in Figure 2.

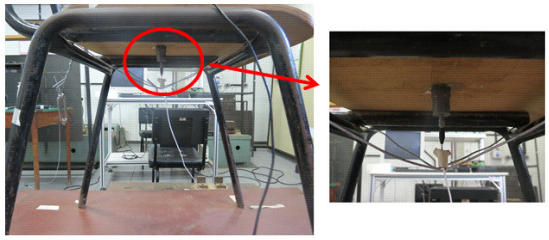

Figure 3: Photo of Control Accelerometer, Model 352A PCB.

The sinusoidal signal was generated by a control system developed in-house. A tri-axial accelerometer APTechnologies AP5213 was placed at the chair seat and connected to a four channels analyzer, model Photon II from LDS Dactron. On the forth channel was connected an uniaxial accelorometer used for the control system. The measurements were performed using the built in weighting functions of the (ISO2631-1, 1997) for whole body vibration. Therefore, it was the weighted acceleration measured by the accelerometer and provided by the analyzer that was used to adjust the amplitude of the signal sent by the generator up to the desired level for each test performed.

The volunteers sat during the entire length of the test on a chair having wooden seat/backrest and metallic feet positioned on the top of this assembly (see Figure 2).

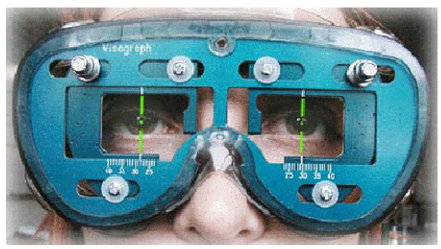

Figure 4: The Visagraph III device (Eye Tracker) used to monitor the eye movement.

During all tests, an Eye-Movement Recording/Assessment System called Visagraph III from Taylor Inc. (Taylor Online Inc., 2008a) (see Figure 4) was used to monitor the reading difficulty in an objective way according to a Taylor National Norm (Taylor Online Inc, 2008b). That device will be refereed as Eye Tracker from now on. The reading time was monitored using a regular chronometer.

3. EYE TRACKER INFORMATION

The saccadic moment of the eyes (Wikipedia, 2009) was monitored using goggles (Eye Tracker device) placed by the examiner over the volunteer´s eyes, adjusted in relation to the volunteer´s pupil, as already shown in Figure 4. It records, among other parameters, the saccades, the eye fixations and regressions with the use of infrared sensors positioned in front the eyes and adjusted in relation to pupils. Since it is attached to the head, the system eliminates the alignment of the participants.The volunteer then had to read a short text selected among the options available inside a text booklet.

The pattern of eye movements are analyzed automatically and then reading objective parameters are generated. Saccades and line changes were located and the first and last lines of each text were discarded by the software, in order to avoid extreme values. For the rest of the text, all reading parameters are calculated and analyzed.

The evaluation of ocular movement was performed throughout all the tests with the Visagraph glasses on. The levels of texts understanding were not evaluated.

3.1 Objective Parameters Used

As mentioned in the previous section, the software included with the Visagraph III eye tracker device records several different parameters to monitor the eye-movements over text. They can be used to evaluate the text reading degree of difficulty. Some of them are used in the current work as analysis parameters, others will only be presented for completeness. The parameters chosen are: 1) fixation (#F), 2) regression (#R), 3) average span recognition (ASR) and 4) Reading Rate (Words per Minute: WPM). Fixation means how many times the volunteer fixed their eyes to read the text and so, more fixations translate a poorer reading. Regression means the eye movement to return to the previous word, that is, the bigger the number of regressions, the worse (more difficult) is the reading. The average span recognition is a variable that tells the capability of the reader to span the words in the text. Therefore, it measures the visual field the subject can read. The goal of this variable is the bigger the span, the better is the reading. The Reading

Rate tells who many words the volunteer reads per minute. Therefore, for a better reading, the number of words read has to be high.

The other variables presented, although not discussed further, are the average duration of fixation (ADF), the global level of efficiency (GLE), the cross correlation (CC) and the directional attack difficulty (DAD) (Taylor Online Inc, 2008b). The goal for these parameters is a small value for all of them, except for the GLE.

In summary, a good reading will have a small number of fixation and regressions and a big value of span recognition and reading rate.

4. METHODOLOGY

4.1 Sample Information

The sample consisted of thirty young people (eighteen men and twelve women), with mean age of 22.6 ± 3.34 years, height of 1.71 ± 0.08 meters, weight of 68.98 ± 11.99 kg and BMI (Body Mass Index) of 23.44 ± 3.07 kg/m^2. Before the tests were conducted, all volunteers signed a Term of Free and Informed Consent (TCLE) and also gave information about their health status. They have no history of visual changes or reading difficulties.

Before all the tests start, each volunteer was interviewed to rule out contraindications to WBV and verification of inclusion and exclusion factors provided for the sample, (Griffin, 1996) and (ISO8041, 1990). The visual distance between the reader and the reading material was measured, as well as the blood pressure and heart rate pre- and post-test to be compared, although such values are not going to be presented in the present work.

4.2 General Information

This study was approved by the Ethics Committee of Research on Human Beings of UFMG. Data were collected in the Laboratory of the Group of Acoustics and Vibration in Human Beings (GRAVI$_{SH}$) of the Mechanical Engineering Department of the UFMG's Engineering School.

The texts were printed both on an A4 white bond paper, Arial black size 12 font, 1.5 line spacing as well as on a tablet (Ipad mini) with the following features: capacity: 16 GB, height: 200 mm (7.87 inch), width:134.7 mm (5.3 inches), thickness: 7.2 mm (0.28 inch), weight: 308 g (0.68 lb), Multi-Touch screen 7.9-inch (diagonal), retro illuminated by LED and IPS technology 1024 x 768, 163 pixels per inch (dpi).

In order to evaluate the reading efficiency using different media types and under different vibration levels, four (4) tests were performed. They are going to be referred as tests A, B, C and D. Reading on the first two tests was performed on an A4 white paper, and on the last two tests was performed on an IPad® mini, so to compare the reading generally performed with the reading using a new mobile technology. Therefore, besides the change of media, there was change on the vibration excitation. Two tests were performed under no vibration and two with vibration at the Z-axis, 5 Hz and 0.8 m/s² r.m.s. The frequency used was chosen since at this value the greatest STH (Seat-to-Head) transmissibility for seated subject occurs (Liang, et al., 2006). The used amplitude value was selected since it is the value normally encountered at normal means of transport (Balbinot, 2001).

The Eye-Movement Recording/Assessment System called Visagraph III (as presented in section 2) was used to record/analyze the data. The system recorded the eye movements made by both the right and left eyes. Each volunteer silently read one different text for each test. It was not required a predetermined postural pattern for each test. Also, there were no pre-established visual distances to their realization. It was left to the volunteers' discretion how to hold the text: with one or both hands. Also, no instruction was given on how to sit on the chair. The reading was performed with the volunteer seated on the chair of the vibrating platform and the volunteers' shoes and feet staying flat on the floor, arms free and/or supported on the thighs or near the trunk. The position was chosen in accordance the preference or the most comfortable position for the volunteer who could choose whether to keep or not his back against the backrest of the chair.

The duration of all 4 tests was around 55 minutes for each volunteer and they were performed on a single day on the order presented in Table 1. This table shows the characteristics of each test performed.

Table 1 – Test Parameters

Test	Media	Vibration	Frequency	Amplitude
A	Paper	No	0 Hz	0 m/s^2
B	Paper	WBV	5 Hz	0.8 m/s^2
C	Tablet	No	0 Hz	0 m/s^2
D	Tablet	WBV	5 Hz	0.8 m/s^2

5. RESULTS AND DISCUSSION

Of the 30 volunteers interviewed initially, 60% used slippers during the tests, 46.66% uses bus as a primary means of transport, 70% do not have the habit of reading in transit, 72.42% were calm to be submitted to the tests, 46.66%

spends their hours of research/study reading on electronic papers against 43.33% reading on conventional paper and 70% of these students prefer to read seated on a hard surface with the reading material supported on a table. There were no statistical differences found in this research between these findings, anthropometric data and the performance of eye movements in the tests.

The main complaints after the tests, included physical discomfort, difficulty to read on tablet caused by reflections on your screen, feeling text "blurred", eyestrain, difficulty focusing, dizziness and malaise by feeling cold and physical tiredness, and nervous irritability. The perception of visual blurring may have been caused by image movement on the retina and may be related to the amplitude and frequency of vibration, as mentioned by (Griffin, 1996). These findings also confirm Po-Hung Lin (2008) which states that the influence of brightness is worse in the electronic paper than in other VDT (visual display terminal) due to direct reflection of light from the surface to the human eyes.

Some physiological responses to the WBV may be influenced by the body biodynamic responses. However, in short exposures, the effects are often small compared with the inter-subject variability of the image motion on the retina. Parameters such as heart rate and blood pressure, measured in this test, increased by 5.45% in the post-test, confirming the positive relationship between increasing symptoms and a sinusoidal vibration at the Z axis, as verified by Jiao et al (2004), Kubo et al (2001) and Griffin (1996).

Table 2 shows the oculomotor results for the tests performed in absolute values. All measured parameters are presented, although only the first four are used during the analysis performed in the current study. The first column presents the test labels, the second column shows the valid number of values used in the analysis and the following columns provide the mean absolute results obtained for each objective parameter considered. The number of valid N sometimes is small as some tests had problem to record the data.

Table 2 – Oculomotor Results for the tests performed (absolute values)

Test	Valid N	Variable	Fixations (#F)	Regressions (#R)	Avg. Span Recog.	Avg. Duration of Fixation	GLE	Cross Correlation	Directional Attack Diffic.	Reading Rate (wpm)
A	50	Mean	132,680	35,060	0,844	0,185	8,700	84,958	23,167	279,320
B	10	Mean	132,000	40,700	1,100	0,169	9,180	79,600	29,200	419,200
C	6	Mean	114,833	25,000	0,948	0,187	9,767	78,000	23,667	309,667
D	4	Mean	86,500	21,000	2,128	0,163	11,900	83,500	28,500	865,500

Figure 5 shows the results of the first four parameters, however, presented as a percentage of the maximum value as presented in Table 2, in order to easy the results comparison. The numbers at each column are the percentage value for each test variable. An explanation about the test configuration is presented besides each test label to simplify the interpretation of the results.

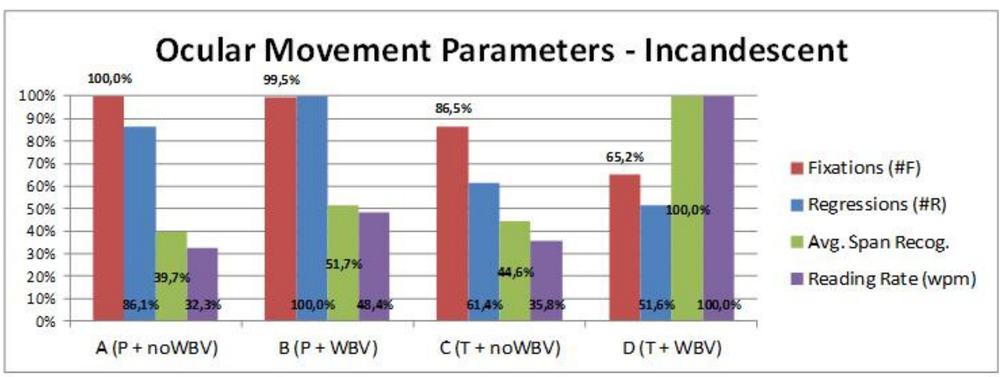

Figure 5 – Ocular Movement Parameters (Percentage in terms of the Maximum).

The responses of the eyes movements found in this study varied maybe due to the fact that the system is non-linear and the responses dependent on the movement predictability. In addition, there was an association of two types of media to head and hands movements caused by the WBV, used in an illuminated and vibratory environment with temperature around 23 °C. It is known that the combination of stressors such as these may interferes with the human responses to mechanical vibration and one cannot explain them properly without considering interference of the central nervous system on them, as outlined by Griffin (1996).

In summary, one can say that a good reading must have a small numbers of fixations and regressions, a large span of recognition, high GLE and higher reading rates. Thus, one can point out that the ocular parameters obtained in this study (see Table 2 and Figure 5) suggest that:

- In the absence of WBV (Tests A and C), the reading performed in conventional paper (Test A) requires more eye fixations and regressions. This means that the volunteers spent more time fixing, on the fovea, the word image/letter read, and that the eyes had to do more movements to return to the previous word. This indicates greater difficulty in reading. On the other hand, the tablet reading (Test C) allowed higher percentage span (ASR), enabling greater character recognition within the visual field, a greater degree of efficiency (GLE) and a larger number of words read (WPM) per minute which make the best reading.

- In the presence of WBV (Tests B and D), reading on paper (Test B) was more difficult to accomplished due to a higher average number of eye fixations and regressions, while the tablet reading (Test D) allowed higher span recognition (ASR) higher degree and longer reading efficiency with both eyes working synchronously (verified by a large binocular correlation - CC). Consequently, there were a greater number of words read per minute indicating a better reading performance.

- The reading parameters obtained in a conventional paper (Tests A and B) show that under WBV (Test B), a larger span allows a better recognition of letters/words (ASR), a higher degree of efficiency (GLE) and a larger number of words read per minute (WPM) under these conditions, although it caused larger number of regressions, despite the fixations being similar.

- The findings also point to better read performance in the tablet under WBV. These findings point to the fact that the WBV may have some beneficial effect on reading performance, as verified by Lynderg et al (2007) and Thulier et al (2008).

As mentioned, this study was performed with WBV on the Z axis and 5 Hz frequency. It is known that random vibrations tend to have less effect on the readability of that sinusoidal vibration at the same frequency and the same r.m.s amplitude. Moreover, vibration in two axes tends to decrease the readability much more than at the single axis vibration (Grifin, 1996).

With respect to the WBV parameters, their transmissibility for a seated individual tends to be higher around 5.5 Hz. In addition, the WBV at 5 Hz produces a movement of the head in space and resonance of the head can happen (Honick (1969) apud Griffin (1996)). It is also known that the WBV in the Z axis can cause translational and rotational movement of the head in all axis (Griffin, 1996). The oculomotricity data presented here may be justified on these grounds.

The results show that reading under WBV requires sharpness of the image on the retina, despite the oscillatory movements of the head and eyes caused by vibration that may decrease the image length of stay in the fovea. It also requires that the eye movements and fixations, saccades and regressions are made from the rotation of the eyes in their sockets and they are adjusted depending on the visual task, as mentioned by Lane (2005). Griffin (1996), however, points out that many nonspecific effects can alter the performance of a person who is under vibration. Some of them will be dependent on the sensation produced by stress and tend to depend on the amplitude, frequency and axis of vibration in a manner similar to those equivalents in a comfort situation.

6. CONCLUSION

Although the results show changes in reading performance under WBV in the Z axis, 5 Hz frequency and amplitude to 0.8 m/s^2 r.m.s. compared with static reading, a fairly significant interaction between eye movement and media type cannot be generalized. Issues related to the intra and inter-subject variability are very important and should be considered when one wants to understand the effects of the WBV on vision or visual tasks such as reading.

Nevertheless, from the results obtained here, one can say that the best reading was under the influence of WBV and performed on tablet. However, the number of data used in such analysis is small, what may have influenced the analysis. Therefore, a suggestion is made to increase the number of valid data in order to make than comparable in all tests.

7. REFERENCES

BALBINOT A. Characterization of Vibration Levels in Bus Drivers: A Focus on Comfort and Health (In Portuguese) // **D.Sc. Thesis**, Federal University of Rio Grande do Sul (UFRS). - Rio Grande do Sul/RS : [s.n.], 2001.

BHIWAPURKAR, M. K.; SARAN, V. H.; HARSHA, S.P. Objective and subjective responses of seated subjects while reading Hindi newspaper under multi axis whole-body vibration. **International Journal of Industrial Ergonomics**, doi:10.1016/j.ergon.2011.06.004, v. 41, n. 6, p. 625-633, 2011.

Duarte M. L. M. [et al.] Effect of Word Spacing on Reading When Submitted to Different Amplitudes of Whole-Body Vibration (WBV) [Conference]. - Gosport/UK : 45th UK Conference on Human Response To Vibraiton, 2010b.

DUARTE M. L. M. [ET AL.] Objective Evaluation of the Influence of the Whole Body Vibration (WBV) Amplitude During Reading, **CONEM2010,** Campina Grande/PB :, 2010a.

DUARTE M. L. M., ARENALES G. G. R. AND FARIA L. N. Is There any Difference Between an Objective and Subjective Evaluation of Reading Difficulty due to Whole Body Vibration (WBV)?, **COBEM2009**, Gramado/RS : 2009.

DUARTE M.L. M. [ET AL.] Effect of The Word Spacing On Reading When Submitted To Different Amplitudes of Whole-Body Vibration (WBV), **HRV2010, 45th United Kingdom Conference on Human Response to Vibration.** - Gosport : Institute of Naval Medicine, 2010.

DUARTE M.L. M. [ET AL.] Objective Evaluation of the Influence of Whole-Body Vibration (WBV) Amplitude During Reading, **CONEM2010, VI Congresso Nacional de Engenharia Mecânica.** - Campina Grande/PB, 2010.

GRIFFIN, M.J. **Handbook of human vibration**. London: Academic Press, 1996.

GRIFFIN, M.J. Whole-Body Vibration. In **Encyclopedia of Vibration,** 2001.

GRIFFIN, M.J.; HAYWARD, R.A. Effects of horizontal whole-body vibration on reading. **Applied Ergonomics**, v. 25, n.3, p. 165-169, 1994.

HANCOCK R. [ET AL.], Influence of Vibration on Workload While Reading and Writing on Indian Trains, **International Conference of Contemporary Ergonomics**. - Nottingham/UK : Taylor & Francis LLC., 2008. - pp. 1-3. - ISBN 13878-0-415-43638-0.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION **ISO8041**, Human Response to Vibration - Measuring Instrumentaion. - Geneve : International Standard Organization, 1990.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION **ISO 2631-1**. Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration. Part 1: General requirements, 1997.

JIAO, K.; LI, Z.; CHEN, M.; WANG, C.; QI, S. Effect of different vibration frequencies on heart rate variability and driving fatigue in healthy drivers. **International Archives of Occupational and Environmental Health**, v. 77, n. 3, p. 205-212, 2004.

KUBO, M.; TERAUCHI, F.; AOKI. H.; MATSUOKA.Y. An investigation into a synthetic vibration model for humans: An investigation into a mechanical vibration human model constructed according to the relations between the physical, psychological and physiological reactions of humans exposed to vibration. **International Journal of Industrial Ergonomics**, v, 27, n. 4, p. 219-232, 2001.

LANE, K.A. Eye Movements and Reading. **Developing Ocular Motor and Visual Perceptual Skills**, p. 10-16, 2005.

LEWIS, C.H.; GRIFFIN, M.J. Predicting the effects of vertical vibration frequency combinations of frequencies and viewing distance on the reading of numeric displays. **Journal of Sound and Vibration,** 1980.

LIN,Y.T.; LIN, P.H.; HWANG, S.L.; SHIE, C.J.; LAO, C.C. Investigation of legibility and visual fatigue for simulated flexible electronic paper under various surface treatments and ambient illumination conditions. **Applied Ergonomics** 40 (2009) 922-928, 2009.

LIANG C-C. AND CHIANG C-F. A Stuy on Biodynamic Models of Seated Human Subjects Exposed to Vertical Vibration, **Intern. Journal of Industrial Ergonomics.** - 2006. - 36. - pp. 869-890.

MANSFIELD, N. **Human Response to Vibration.** Nova Iorque: CRC Press, 2005.

PO, H.L.; LIN, Y.T.; HWANG, S.L.; JENG, S.C.; LIAO, C.C. Effects of anti-glare surface, ambient illumination and bending curvature on legibility and visual fatigue of electronic papers. **Displays**, v. 29, p. 25-32, 2008.

RAYNER, K. Eye movements in reading and information processing: 20 years of research. **Psychological Bulletin**, v. 124, p. 372-422, 1998.

SHEN, I.H.; SHIEH, K.K.; CHAO, C.Y.; LEE, D.S. Lighting font style and polarity on visual performance and visual fatigue with electronic paper displays. **Displays**, v. 30, p. 53-58, 2009.

SUNDSTRÖM, J.; KHAN, S. Influence of stationary lateral vibrations on train passengers'difficulty to read and write. **Applied Ergonomics**, v. 39, n. 6, p.710-718, 2008.

TAYLOR ASSOCIATES/COMMUNICATIONS, I. **Visagraph III - Resource Guide**. New York, 2006.

THULLIER, F.; LEPELLEY, M.C.; LESTIENNE, F.G. An evaluation tool for psychomotor performance during visual motor task: an application of information theory. **Journal of Neuroscience Methods**, v. 171, n. 2, p. 183-189, 2008.

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9. RESPONSIBILITY NOTICE