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WHAT IS THE EFFECT ON THE TIME TAKEN TO WRITE UNDER THE INFLUENCE OF WHOLE BODY VIBRATION (WBV)?

Maria Lucia Machado Duarte [a]
Luiz Otavio Mendes Duarte [b]
Lázaro Valentim Donadon [c]
Universidade Federal de Minas Gerais (UFMG), Mechanical Engineer Department (DEMEC), Group of Acoustics and Vibration in Human Beings (GRAVIsh), Avenida Antônio Carlos, 6627-Belo Horizonte, MG, 31.370-440, Brazil.
[a] mlduarte@dedalus.lcc.ufmg.br
[b] luizotavio.mduarte@gmail.com
[c] lazaro@demec.ufmg.br

Luciana Gomides [d]
Universidade Federal de Minas Gerais (UFMG), Post-Graduation Program in Mechanical Engineer (PPGMEC), Group of Acoustics and Vibration in Human Beings (GRAVIsh), Avenida Antônio Carlos, 6627-Belo Horizonte, MG, 31.370-440, Brazil.
[d] luciana.gomides@paulwurth.com

Abstract. *Whole Body Vibration (WBV) is a physical agent present in the daily life of people. The main sources are vehicles in general and machines which may transmit the vibration not only directly to the operator, but to the surroundings as well. Faced with this reality, it is very common the situation when a subject has to write something over the influence of whole body vibration (WBV). Depending on the frequency and amplitude of excitation, such task may be very difficult. Both the hand and the head (eyes) vibration play a part on such performance. However, some people may have developed a way of overcoming such difficult. The aim of this study is to investigate the influence of WBV on writing by analyzing the time taken to perform the task. For that, a group of volunteers (men and women of different ages) were subjected to a 5 Hz sinusoidal vertical WBV with 0.8* m/s^2 *amplitude. No control of the HAV(Hand Arm Vibration) or head vibration will be made. The WBV amplitude will be measured at the seat. The tests were performed in the laboratory of the Group of Acoustics and Vibration in Human Beings of the Universidade Federal de Minas Gerais (*$GRAVI_{SH}$*). Three measurements were made: writing without vibration, writing under the mentioned vibration exposure, followed by writing some time after the effect of vibration. The time to perform each task was recorded. So, the three times are compared to verify if there is an effect of the WBV on the writing performance and to check if the vibration causes any residual influence.*

Keywords: *Whole-Body vibration (WBV), Writing, time.*

1. INTRODUCTION

Due to the constant technological advances in safety and comfort at the automotive industry, commercial vehicle's manufacturers have sought to ensure the reduction of vibration to the human body, without compromising safety criteria and vehicle's components strength (Balbinot, 2001). The cost reduction associated to both the project and the manufacture of automotive components, requires the development of more accurate and effective analytical tools for analyzing the mechanical response of structural and mechanical components that make up the various subsystems of the vehicles so to provide the desired vibration reduction. The subject needs to be considered part of the system when the objective is to provide comfort or even when some task has to be performed under vibration.

WBV (Whole Body Vibration) usually occurs when the whole environment is subjected to movement and the effect of interest is not a particular position. It may be produced by machinery, building vibration, vehicles and earth movement, among others. It is common the situation when the subject is inside a vehicle (or building) and needs to perform some writing or even another manual task. The vibration excitation from these sources should not interfere in such activities.

The parameters used in this work are found in vehicles, since that is the main application of the current research, which seeks to understand the influence of WBV on writing in such environment. What varies from one type of vehicle to the other is the main frequency and amplitude a subject is submitted when in WBV. Some typical vehicles´ characteristics are shown in (de Oliveira, 2007) and (Balbinot, 2001). From such references, it was possible to see that the main frequency of most vehicles is around 4 to 8 Hz. Besides, in this range the weighting curves of the (ISO2631-1, 1997) are close to unity, decreasing therefore, its influence on the results obtained, although the weighting curves were questioned in (Morioka, 2008). Moreover, (Liang, 2006) showed that the highest seat-to-head (STH) transmissibility occurs around 5 Hz, minimizing the level of excitation necessary for the subject to feel the vibration.

The human body is a complex mechanical system that does not respond to vibration in the same way as a rigid body, since there is relative motion between the body parts that vary with frequency and direction of vibration application.

The dynamics of the body affects all human responses to vibration (Griffin, 1996). Only for frequencies below 2Hz during vertical sinusoidal vibration, most of the body moves up and down as a rigid body. The highest frequency of amplification (resonance frequency) varies for different body parts to different individuals and posture changes (Griffin, 1996). Table 1 shows some frequency values where resonances occur in different parts of the human body, according to (Misael, 2001). The human body is a sophisticated biomechanical structure and its sensitivity to vibration may involve several factors, such as posture, muscle tension, frequency, amplitude, direction, duration and dose of exposure. According to (Griffin, 1996), vibration at different frequencies or axes can produce different sensations and influences in different parts of the body and when the amplitude increases, usually increases the discomfort and also the interference on the performance of tasks.

Table 1. Resonance frequencies of the human body parts

Human Body Parts	**Resonance Frequency [Hz]**
Head	20 to 40
Spine	8
Abdomen	4 to 8
Shoulders	4 to 8
Lungs	4 to 8
Hands and Arms	20 to 70
Eyes	60 to 90
Source: (Misael, 2001)	

Although the hands and arms system in Table 1 shows resonance frequencies around 20 to 70 Hz, that is not the most important frequency range for writing activities. (Griffin, 1996) studied the effect of WBV frequency in the vertical direction (z-axis) on the quality and velocity of writing. He showed that the writing clarity can be affected by both the frequency and amplitude of vertical vibration. It was demonstrated that the illegibility of writing in the 4-8 Hz frequency range is due to the relative big displacement of the arm-hand system in these frequencies. The vibration effect on writing depends also on the posture and position of the subject and therefore, varies between them. The influence of the STH transmissibility may also play an important part in these results.

Understanding how the vibration is transmitted to the human body is a requirement to fully understand how the vibration influences on human comfort, in the performance of tasks or even in the health. The deleterious effects of Whole Body Vibration on health are different. Among the most commons one can cite problems on: spinal cord, digestive system, genital / urinary system and female reproductive system (ISO 2631-1, 1997), (Griffin, 1996).

(Bhiwapurkar, 2011) investigated the interference perceived in sketching geometric figures such as circle, rectangle and triangle under vibration environment in two subject postures (sketch pad on lap and on table) under low frequency random vibration in both mono and dual axes. Random vibration stimuli were excited in various axes in frequency range of 1-20 Hz at magnitudes of 0.4, 0.8 and 1.2 m/s^2. Three performance methods were used to measure the effect of vibration stimuli and posture. He showed that the percentage distortion and difficulty in sketching increased with an increase in vibration magnitude and was found to be higher for vibration in y- and z-axis (ISO2631-1, 1997). Similar trend was observed for percentage distortion and difficulty in sketching for dual axes also. The perceived difficulty and impairment in sketching performance was greater while sketching on lap for x-axis, while the effect was just the reverse for other axes. He shows that the vibration magnitude is the highest influencing factor on the perceived difficulty and percentage distortion in sketching and has good correlation with all the performance measures.

(Harris, et al., 2002) mention that an unique relationship between vibration and task performance is unlike and that the influence of WBV on writing and drinking is common to happen in public transportation vehicles and ships. The How the vibration will influence depends on hand motion, the type of control, and the dynamics of the control and the controlled system. They mentioned that a control that responds to hand displacement may be interrupted by vertical vibration at frequencies between 2 and 6 Hz. The effect of the duration of vibration exposure on task performance is influenced by motivation, arousal, and adaptation and may therefore be observed to improve or degrade performance over time.

(Corbridge, et al., 1991) investigated the influence of WBV on activities performed by passengers of public transport, such as writing, drinking and hold a coffee mug. The results revealed that for vibration around 4 Hz, 85% of the volunteers spilled liquid even in low amplitude vibration. For frequencies below 3 Hz or above 5 Hz, only for 10% of the volunteers that fact happened.

According to (Griffin, 1996), complex manual-control systems rarely show a high response to disturbances in the region of 4 Hz, where the dynamic response of the body dictates the greatest probability of breakthrough due to vertical motion. At lower frequencies to restrict the movement may be feasible. In the same work he shows a study on writing varying the frequency and amplitude of WBV. It is possible to see that 5 Hz was the frequency with most effect on writing and since that is within the scope of vehicles, it was the value chosen for the present study.

This work has as main goal to study the effects of Whole-Body Vibration (WBV) in writing. The focus of the analysis is to evaluate the time spent by each subject to perform this task. A test procedure has been defined and a group

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of volunteers (male and female of different ages) were subjected to a vertical WBV. The evaluation methodology and the testing procedure are described below.

2. EXPERIMENTAL METHODOLOGY

2.1 Sample Selection

All volunteers who attended the tests were students of the Mechanical Engineering Course of the Federal University of Minas Gerais (UFMG), due to, but not only, the easiness of recruitment. The sample was composed by 14 health volunteers (3 women and 11 men) with average age of 21.43±1.7 years, average weight of 70.0±9.3 kg and average height of 1.75±0.07 m. The volunteers were selected after answering questions about their health and other factors that could interfere with their participation on the tests as recommended in (Griffin, 1996) and (ISO13090-1, 1998). They were then informed about how the tests would be performed and signed a term of consent after that.

2.2 Experimental Setup and Instrumentation Used

The tests were performed at the laboratory of the Group of Acoustics and Vibration in Human Beings of UFMG ($GRAVI_{SH}$). Figure 1 shows a sketch of the configuration used and Figure 2 shows a photo of such configuration.

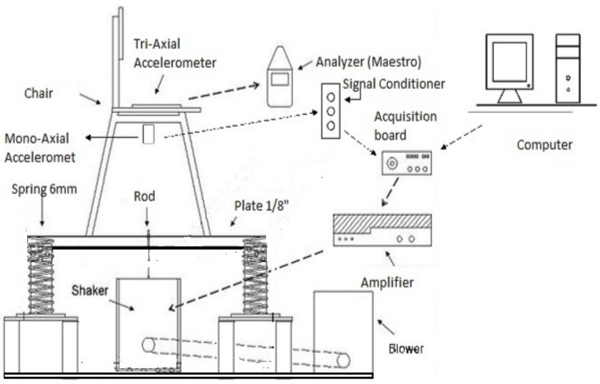

Figure 1. Schematic drawing of the WBV setup and instrumentation.

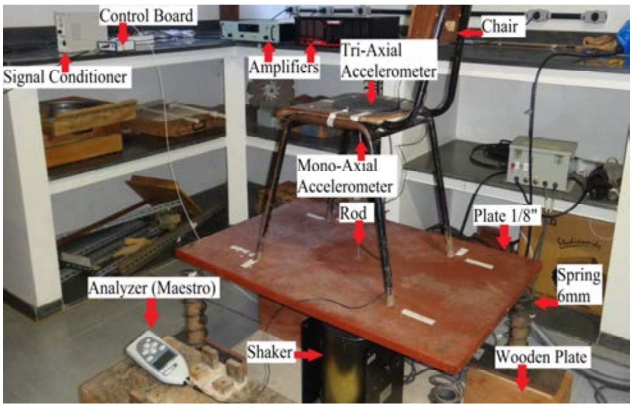

Figure 2. Photo of the setup used for WBV writing tests

The subjects sat in a wooden chain having metallic feet, with backrest but no cushion. It was positioned over a metallic plate (750 x 1000 x 3 mm) with reinforced edges. The position of the chair was such that the center of gravity of the setup (chair + subject) was coincident with the geometry center of the plate, in order to avoid undesirable rotational movements that could damage the shaker. The main excitation was in the z-axis, according to (ISO 2631-1, 1997), as this is the direction of greatest interest for this work. The plate was supported by four 1020 steel compression springs (76 mm external diameter, 350 mm height, 6 mm wire diameter and 9 coils). The excitation was provided by a Dynamic Solution® shaker model VTS150, positioned under the platform. Therefore, due to the height of the shaker, the springs had to be placed on top of wooden plates. A steel push rod with 3.0 mm diameter and approximately 107 mm variable length, with screws at both ends (used to control the height of the push rod according to the weight of each volunteer), was used to transmit the sinusoidal signal used during the tests from the shaker to the platform.

The sinusoidal excitation used during the tests was generated on a control system developed using a National Instrument acquisition board model NI Speed 33 to maintain the excitation at the desirable level (Batista Filho, et al., 2010). Since the output level of the control board is very low, only one amplifier was not sufficient to achieve the necessary level for the test, therefore, two amplifiers were used in a serial configuration (a Crown Amplifier® CE2000 and a B&K 4810 amplifier). The amplified signal was sent to the shaker and measured by an APTechnologies® AP5213 tri-axial accelerometer positioned on the chair seat, using a standard seat pad, (Griffin, 1996). That signal was sent to a portable analyzer model Maestro from 01dB in order to verify if the level used was the state one. For the control system a standard mono-axial ICP accelerometer model 352A from PCB Piezotronics was used. It was positioned under the chair seat. As there is no ICP supply on the control board a signal conditioner PCB Piezotronics model 482A22 was necessary for this mono-axial accelerometer.

The measurements were performed using the built in weighting functions of the ISO 2631-1 (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 time taken to perform the task (writing) was monitored using a chronometer application by Chronus (Chronus, 2013) installed on a cel phone Samsung (model Galaxy Y).

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3. EXPERIMENTAL METHODOLOGY

Before the beginning of each battery of tests, an explanation about how the tests would be conducted was given to the volunteers. Since the objective of the tests were to verify the influence of WBV on writing and in order to standardize as much as possible to variables that could interfere in such task, instructions on how the volunteers should be over the platform and how the writing should be performed were given.

All volunteers sat in the chair with one leg crossed on top of the other and the supporting foot completely flat on the floor. The back was against the back rest of the chair. The writing was performed using a common black ballpoint pen. The sheet used was guided and was fixed on a clipboard. So, the volunteer supported this clipboard over the folded leg. Figure 3 shows details of such positions.

Figure 3. Volunteer and clipboard position during the tests.

The tests consisted of writing the following phrase “Teste para verificar VCI na escrita”. No instructions were given on the type of letter used, therefore, leaving such option to the usual writing of the volunteer. Three tests were made as shown in Table 2. (T1) was performed under no vibration, (T2) under WBV in 5Hz, 0.8 m/s^2 and z-direction and (T3) again under no vibration in order to verify the residual influence of the WBV. Although it will not be the objective of this article, the volunteers after the task being performed had to evaluate the difficulty level using two different scales (both numeric and conceptual). Therefore, (T3) was performed immediately after these evaluations, which lasted in average 30 sec. The parameters of the vibration used were based on other studies (Griffin, 1996), (Bhiwapurkar, 2011) and tries to represent that found in vehicle, as mentioned in section 1.

Table 2. Test parameters.

Test number	Description	Frequency	Amplitude
T1	No WBV	x	x
T2	With WBV	5 Hz	0.8 m/s^2
T3	No WBV (residual effect)	x	x

The tests were recorded using a web-cam (C3 Tech) for further analysis if necessary. No measure of the hand-arm-vibration (HAV) or head vibration (HV) was made. As mentioned in section 2.2, the time to perform each test was monitored. Each writing for each test (T1, T2 and T3) shown in Table 2 was performed only once.

4. RESULTS AND DISCUSSIONS

The influence of WBV on writing can be seen on Figure 4 and Figure 5. The first figure shows the absolute time spent by each volunteer during the writing proposed under each of the test configuration shown in Table 2. The latter figure shows the relative time between T1 x T2 and T1 x T3. There, the first comparison (left bar for each volunteer) is to check the WBV influence and the second comparison (right bar for each volunteer) is to check the residual influence of the WBV. The mean time to write the phrase of each test considering all volunteers is presented in Table 3. It can be seen that the average time increased 13.8% under the influence of vibration (T1 x T2), however, there was no residual effect after the writing being performed after the WBV being suppressed.

The results of Figure 5 also show that the performance on writing for the posture adopted decreased the ability of writing for 12 volunteers (86% of the sample). Only 1 volunteer (7%) had no influence of WBV on writing and 1 volunteer decreased his/her time under WBV influence. Since it was necessary to stabilize the vibration before the task being performed, the actual total WBV exposure for each volunteer lasted between 1 to 2 minutes. Such duration is less than the usual exposure people are subjected every day. Therefore, it is possible that the performance will degrade even more over longer periods of time. However, such hypothesis needs to be explored in further work.

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Although the average time did not shown any significant difference in result between the tests with no vibration (T1 x T3), it can be seem that only 4 volunteers (28.6%) had no residual influence on writing. Four (4) volunteers (28.6%) increased their time after the WBV exposure and 6 volunteers (42.8%) decreased the time after this exposure.

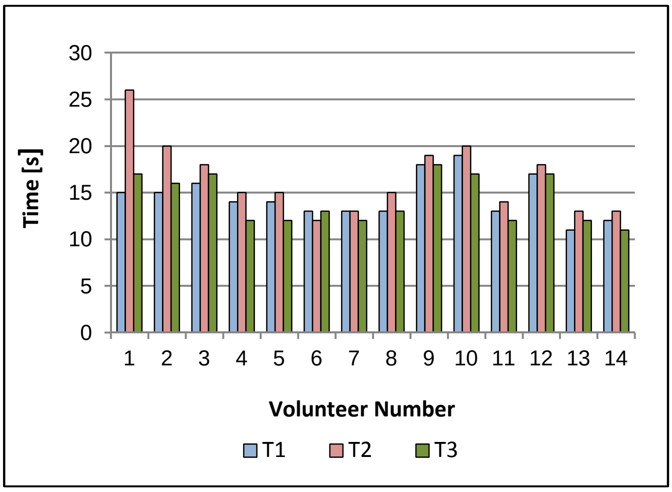

Figure 4. Absolute writing time for all tests (T1, T2 and T3) for each volunteer.

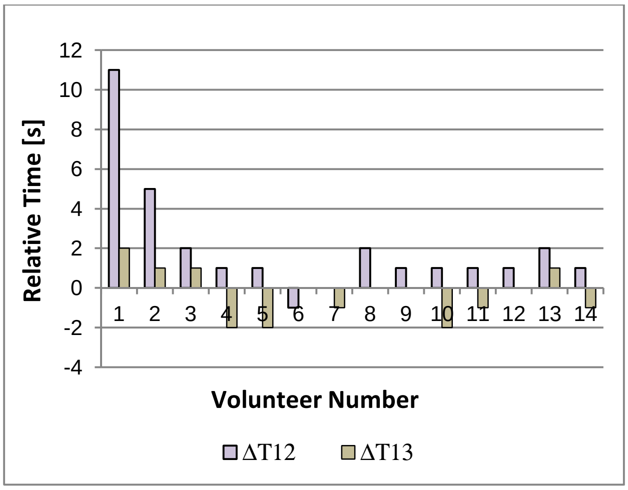

Figure 5. Relative writing time between tests T1xT2 and T1xT3 for each volunteer.

Table 3. Mean writing time (all tests).

Test number	Description	Mean Writing time [s]
T1	No WBV	14.5±2.3
T2	With WBV	16.4±3.9
T3	No WBV (residual effect)	14.2±2.6

A statistical analysis was performed to verify if the results are statistically different. For that, the repeated measures analysis of variance (ANOVA) was used to test for any significant main effects of WBV exposure (T1, T2 and T3). The Bonferroni post hoc test was used following the ANOVA analysis to compare the influence between the conditions. Statistical significance level was accepted at the 5% ($p=0.05$). Therefore, any "p" value higher than 0.05 shows no influence of WBV, whereas the opposite means that WBV plays an important role on the result. The results are shown in Table 4. Therefore, the statistical analysis confirms the previous conclusions, that is, WBV (T2) influences on the writing time when compared with T1 (no vibration) and there was no residual influence of WBV ($p>0.05$) when comparing T1 with T3 (which were performed under no vibration but the latter after the vibration being suppressed).

Table 4. Bonferroni post hoc test results

Comparison	Criteria	p value
T1 x T2	$p<0.05$ (T2 ≠ T1)	0.0083
T1 x T3	$p<0.05$ (T3 ≠ T1)	1.000

The above comments can also be seen in Figure 6 and Figure 7, which shows the time comparison in another format. A linear regression was performed and the equation for that is shown in the figures. If all results were the same, the linear equation would be y = x, therefore, each individual comparison would lay on the 45^0 slope line (dotted line). If not, the highest value will be on the triangular part of the plot closest to that variable. It is not possible to see all volunteers on these plots, as some of the results are the same, therefore, laying on top of each other. As seen in Figure 6 for only one volunteer the results were equal. Since the other results are above the 45^0 line, it shows that the time for T2 was higher than for T1. The slope is almost parallel to the 45^0 line, showing that the variation is somewhat constant. Figure 7 highlights once again that there is no much residual influence of the vibration on the time spent by the volunteers. Since some pairs are above the 45^0 line and some below, the regression equation is almost on the 45^0 line.

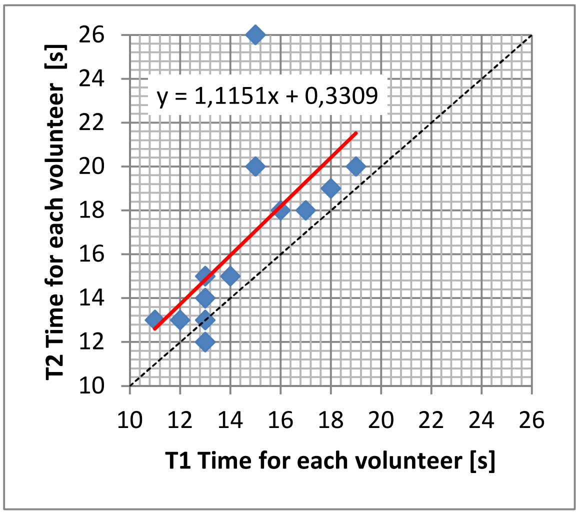

Figure 6. Time comparison between tests T1 and T2.

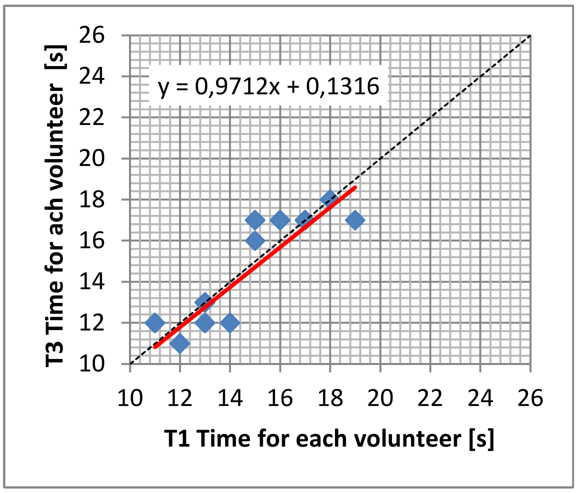

Figure 7. Time comparison between tests T1 and T3.

Even though has been verified here that WBV increases the time taken to perform the writing, such results should be extrapolated to everyday situations with due care, when considering the vibration transmitted by civil structures or vehicles. The reason for this comment is that the present study was laboratorial using only one axis of vibration. Therefore, further investigation is necessary including additional axis, such as y-axis, roll, pitch and yaw movements.

In order to see the influence on writing, some sample of it will be presented. Figure 8 shows the writing for volunteer 6 who was the one that decreased the writing time under WBV between T2 and T1, although showed no time difference between the tests with no WBV (T1 = T3), as seem in Figure 4. It can be said that, although T2 < T1, the writing seems to have been influenced a little bit by the WBV. Figure 9 shows the writing for volunteer 1 that had the highest time variation to write between the tests as seem in Figure 5. It may be inferred that the reason for that was to write more perfect. This may explain why the writing from T1 and T3 is not much different, although the time to perform it is. Figure 10 shows the writing for volunteer 7 that had no time difference T2 and T1, therefore, indicating that WBV had no influence. In fact, the three writings seem very close to each other.

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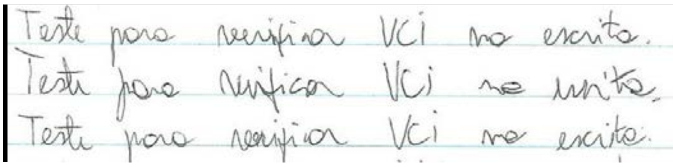

Figure 8. Writing time between T2 < T1 (volunteer 6).

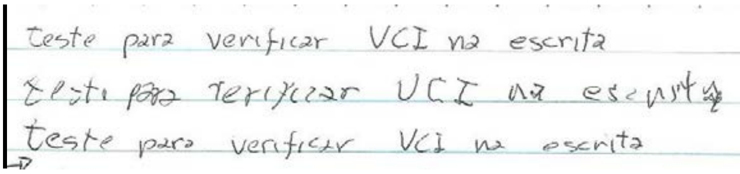

Figure 9. Highest time variation between the tests (volunteer 1).

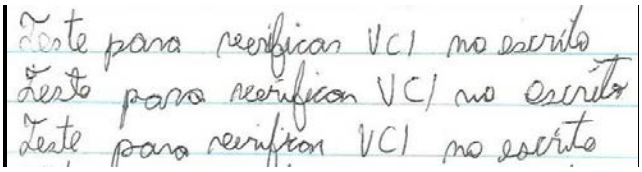

Figure 10. No time change between T1 and T2 (volunteer 7).

5. CONCLUSIONS

This article presented a study on the influence on writing of the WBV at 5 Hz, 0.8 m/s^2 in the z-axis, for a seated subject. It was shown that WBV plays a role on the time to perform the task. Although some of the times measured for the test with WBV were smaller than the one with no vibration, looking at the quality of the writing, it can be seem that there was actually an influence. There was no residual influence of the WBV exposure after it is suppressed.

6. ACKNOWLEGMENT

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