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Effects of occupational vibration exposure on cognitive/motor performance

N. Costa [a, b, *], P.M. Arezes [a, b], R.B. Melo [c, d]

[a] Department of Production and Systems, School of Engineering, University of Minho, Portugal
[b] Research Centre for Industrial and Technology Management (CGIT), ALGORITMI Research Centre, School of Engineering, University of Minho, Portugal
[c] Ergonomics Section, Faculty of Human Kinetics, University of Lisbon, Portugal
[d] Research Centre for Architecture, Urban Planning and Design (CIAUD), Faculty of Architecture, University of Lisbon, Portugal

A R T I C L E I N F O

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A B S T R A C T

Whole-body vibration (WBV) occupational exposure levels were determined with 29 different types of machinery. Two distinct WBV exposure profiles were found and reproduced in a controlled exposure situation that involved the transformation of a vehicle. A sample of 45 volunteer subjects was recruited to assess the effects of WBV on their cognitive/motor performance. Two different tests were selected and applied: an Action Judgment Test, which was primarily designed to examine the relation between the distribution of attention and the resultant reaction to ever-changing conditions, and an Omega Test, designed to examine the precision and attention in handling mechanisms. The results show that the vibration exposure level affects the degree of impairment. The subjects presented a lower performance level when exposed to higher vibration levels, as the time required to correct their errors more than doubled. No significant differences were found when comparing the performance for gender or age variables. The obtained results can be used to improve the characteristics of work vehicles, in order to reduce the corresponding adverse effects and, consequently, improve the corresponding working conditions.

Relevance to industry: The obtained results can be used to highlight the importance to reduce exposure to vibrations in work vehicles, minimizing the associated adverse effects and, consequently, improve the corresponding working conditions.

1. Introduction

Every occupational environment presents numerous risk factors. Exposure to whole body vibrations (WBV) is common, primarily when the work requires the operation of machines such as buses, trucks, forklifts, heavy machinery and other vehicles driven or operated by man. The most often cited effect of exposure to WBV in the literature is self-reported 'back pain.' This is confirmed by several epidemiological studies on the subject (e.g., Bovenzi and Hulshof, 1998; Bovenzi et al., 2006; Magnusson et al., 1998; Gallais and Griffin, 2006). M. Bovenzi and M.J. Griffin are two examples of researchers that have attempted to systematise exposure profiles and the reported symptoms, however, most of their studies (e.g., Bovenzi et al., 2006; Gallais and Griffin, 2006) are focused on the potential effects on the health of workers.

The need to comparatively evaluate cognitive/motor performance in a situation of exposure and non-exposure to WBV emerged from the potential effects evident in the existing literature (Blüthner et al., 2002; Cronin et al., 2004; Jiao et al., 2004; Mansfield et al., 2006; Schust et al., 2006; Lin et al., 2008; Messina et al., 2009; Mani et al., 2010).

Griffin and Hayward (1994) investigated the effects of the horizontal component (*X* and *Y* axes) of WBV on the readability of a text taken from a newspaper. As a variable, the authors used the number of syllables read under vibration exposure and non-exposure conditions. Their primary conclusions indicate a statistically significant reduction in reading speed when subjects were exposed to vibration frequencies in the range of 3.15–5 Hz combined with acceleration values of 1.0 and 1.25 m/s^2. The most significant reduction occurred at 4 Hz for both mentioned values of acceleration (Griffin and Hayward, 1994).

Kubo et al. (2001) proposed a synthesis model of the components involved in the effects of human exposure to WBV. The

* Corresponding author. Department of Production and Systems, School of Engineering, University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal. Tel.: +351 253510360; fax: +351 253510343.
E-mail address: ncosta@dps.uminho.pt (N. Costa).

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authors assumed that the responses of the human body when exposed to vibration can be explained by three sets of reactions: 1) the reaction expressed by the physical transmission of vibrations from one body part to another; 2) the physiological reaction that is manifested by changes in blood pressure, heart rate, etc., and 3) the psychological reaction illustrated by the manifestation of various symptoms induced by the vibrations, such as physical symptoms (tiredness, yawning, sleepiness, tired eyes, and absent-mindedness), mental symptoms (irritation, loss of patience, distracted attention), and nervous symptoms (headache, backache, dizziness, nausea, and stiff shoulders) (Kubo et al., 2001).

Ljungberg et al. (2004, 2007a,b) reported similar results in three separate papers. The authors first began to examine the effects of noise and WBV, combined or isolated, on cognitive performance. Although they did not find significant changes in reaction times, the participants rated combined exposure as more annoying than isolated exposure (Ljungberg et al., 2004). A post-exposure task was proposed by the authors in order to evaluate cognitive post-exposure effects. Performance degradation was revealed in the attention task after exposure to vibration (Ljungberg and Neely, 2007a). Further physiological reactions were investigated, namely the effects on saliva cortisol levels (considered a biological stress marker). The obtained results showed no substantial effect on the physiological stress as measured by saliva cortisol (Ljungberg and Neely, 2007b).

Newell and Mansfield (2008) designed a methodology to evaluate the reaction time to a visual stimulus and the corresponding motor response in order to evaluate the influence of exposure to WBV in conjunction with hazardous working postures on the performance of a task. The task was carried out in five different working postures and involved the presentation of directional arrows in random orders and intervals on a monitor located 1.1 m away from the subject, to which the subject responded by pressing the equivalent arrow on a keyboard. The results demonstrated that exposure to WBV and posture negatively influenced the reaction time and the correct answers of the test subjects. They also found that the reaction time was significantly longer when the subjects performed the task without a chair armrest. Posture was not a significant factor in the increasing number of errors (Newell and Mansfield, 2008).

Jiao et al. (2004) documented a positive relationship between heart rate and exposure to WBV. Based on fourteen subjective symptoms of fatigue, four of them proved to be significantly affected by WBV: an increase in physical tiredness, a desire to lie down, stiff shoulders and a lack of spirit (Jiao et al., 2004).

More recently, Li et al. (2012) found evidence that exposure to WBV also increases the activation of the pre-frontal cortex region, resulting in extra oxygen and energy demands. They suggest that this increased activation may contribute to the development of fatigue in occupations exposed to WBV (Li et al., 2012).

The objectives of the current study are twofold: first, we intend to characterise, as comprehensively as possible, the occupational exposure to WBV of the analysed work vehicles' operators; second, we will evaluate the effects of the exposure to the obtained WBV profiles on cognitive/motor performance.

Several authors have published papers addressing the characterisation of the occupational exposure to WBV (Malchaire et al., 1996; Maeda and Morioka, 1998; Paddan and Griffin, 2002; Funakoshi et al., 2004; Kumar, 2004). However, to the authors' knowledge, none has performed the evaluation of the effects of the exposure in 'real-life' situations. Accordingly, it is the authors' belief that this type of evaluation strategy presents results more close to the real demands of the tasks performed by professional drivers and heavy machinery operators. Being so, this experimental approach can produce new knowledge about the effects of the occupational exposure to WBV, by helping to find new ways to present the information to the drivers and to identify new demands for users' interface design.

2. Materials and methods

2.1. Sample

To pursue the first objective of this study, extensive field work was developed in which the vibration levels of 29 different types of vehicles were measured and assessed, including buses, garbage trucks, fork-lifts, tracked excavators, dumpers, tracked loaders, backhoe loaders, compactors, vibration tandem rollers, wheel loaders and farm tractors.

For the second objective, subjects were randomly selected through individual invitations sent to students, staff, faculty and visiting faculty of a University campus. The considered sample was composed of 45 volunteers (25 males and 20 females) with ages between 21 and 62 years (mean of 33.1 $\pm$ 10.0 years). These 45 volunteers were distributed through five age categories ranging from less than 25 years old (15 subjects), more than 25 and less than 35 years old (11 subjects), more than 35 and less than 45 years old (13 subjects), more than 45 and less than 55 years old (5 subjects), and more than 55 years old (1 subject).

2.2. Exposure assessment

The characterisation of the occupational exposure to WBV was carried out with a real-time vibration analyser (QUEST VI-400pro) equipped with a tri-axial accelerometer (DYTRAN 3143M1). The criteria for measuring and assessing the exposure to WBV followed the guidelines of ISO 2631-1:1997. The considered measurement time ensured an acceptable statistical accuracy and also assured that the vibration measurement corresponded to the 'typical exposure' that was being evaluated. All measurements were performed during the performance of actual tasks with the seat pad accelerometer oriented according to the operators' body axes. The evaluation included three different samples taken during typical tasks confirmed by the machinery operator. The total sampling time was at least 30 min per vehicle.

In order to achieve the second objective of this research, the back of a 2.5 ton van (Citroen Jumper 2.5D) was modified to accommodate two adults and the test equipment. This modification included the introduction of two individual seats and a support platform to accommodate the equipment used to conduct the tests. A pad containing the Dytran tri-axial accelerometer was placed on the seat of the test subject in order to monitor the acceleration values throughout the tests. Thereafter, the values obtained for each test subject would create a profile of exposure and, at the same time, confirm that all tests were performed under similar conditions. The other seat was installed to allow the researcher to assist the test subjects while performing the tests. The driver was alone but was able to communicate with the researcher through radio. The van was always driven by the same person (recruited from the Ergonomics Laboratory staff) to ensure the consistency of the driving tasks during all of the performed tests.

In order to evaluate the effects of exposure to WBV on a potential driver's cognitive/motor performance, it was necessary to ensure that the exposure conditions remained unchanged for all subjects and during all the tests. Therefore, a closed-circuit test road was selected that fulfilled two important criteria: incorporating different types of pavements and ensuring test reproducibility. Regarding the first criterion, two different pavements were selected: regular asphalt and uneven cobblestones. The closed nature of the circuit allowed for the vehicle to remain at a constant