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Hand-arm and whole-body vibrations induced in cross motorcycle and bicycle drivers

L.M. Roseiro [a, b], M.A. Neto [b], A.M. Amaro [b, *], C.J. Alcobia [a], M.F. Paulino [b]

[a] Polytechnic Institute of Coimbra, Coimbra Institute of Engineering, Mechanical Engineering Department, Rua Pedro Nunes- Quinta da Nora, 3030-199, Coimbra, Portugal

[b] CEMUC, Department of Mechanical Engineering, University of Coimbra, Pinhal de Marrocos, Pólo II, Rua Luis Reis Santos, 3020-788, Coimbra, Portugal

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ABSTRACT

Generally, and particularly at sports, the human body is constantly exposed to physical requests and to tests in many different situations. Although the practice of sports is considered a healthy act, there are limits and, when these limits are reached, the benefits of sport can turn into problems. Thus, the biodynamic response method is increasingly being used to study the human injuries induced by external vibrations. Moreover, the European Directive 2002/44/EC on the minimum health and safety requirements, regarding worker exposure to risks from physical agents (e.g. vibration), limit the exposure to vibrations. The aim of this study is to analyze the exposure level of cross motorcycle and of cycling drivers to hand-arm vibration (HAV) and to whole-body vibration (WBV). For this research, vibration levels of a common 200 cc cross motorcycle were experimentally measured and the maximum driving time that could be safely used in a stone road was established. Moreover, bicycle vibration measurements were performed using two different bicycles: a road cycling bike; a bike for track cycling. The road bike was evaluated at three road scenarios: asphalt; paved; and stone road pavement. The track bike was evaluated in track cycling and rollers. In the case of cycling the results indicate that impacts and transient vibrations lead to a higher musculoskeletal request particularly in what concerns shoulders, arms, wrists, knees and spine.

1. Introduction

Disorders of muscle tissues and of their surrounding structures, i.e., musculoskeletal disorders (MSDs), indicate health problems of the locomotor apparatus, (Roman-Liu, 2013). MSDs mostly result from cumulative effects of long-lasting loads of various magnitude, resulting from a wide range of external factors at the work environment and at the daily life. Thus, MSDs depend on both occupational and non-occupational factors (Habib et al., 2012; Choobineh et al., 2011). Several epidemiological studies have proved that biomechanical load, vibration and psychosocial factors may contribute to the development of MSDs in several body parts (Punnett et al., 2005; Bovenzi, 2008; Smith et al., 2006).

The human exposure to vibrations is classified according to his peculiarities into whole-body vibration (WBV) and hand-arm vibration (HAV). These two types of vibration have different sources, affecting different areas of the body, and produce different symptoms. WBVs are transmitted to the human body through the seat or feet, or both, often, when driving motor vehicles or by standing over vibrating floors. These kinds of vibrations are of low frequency and high amplitude, and are in the range 1–80 Hz, specifically 1–20 Hz. HAVs, on the other hand, are limited to hands and arms and, usually, they result from using power hand tools and from vehicle control. HAVs are the most studied and they lie in the range of 6.3–1250 Hz. The vibration effects on the human body are dependent on the frequency of vibration (Sezgin and Arslan, 2012). Yang et al. (2015) studied the effect of dual-frequency WBV session in both vertical jumping and COD (change of direction) ability in rugby players, and had concluded that the type of frequencies could improve COD ability as well as vertical jump height in athletes. Nevertheless, the human response to vibration is dependent on a number of factors that are difficult to quantify, including the interaction between the body and point of contact (or coupling), the posture of the body, the biodynamic properties of the individual, and environmental considerations (Thrailkill et al., 2013).

* Corresponding author. Department of Mechanical Engineering, University of Coimbra, Portugal.

E-mail addresses: lroseiro@isec.pt (L.M. Roseiro), augusta.neto@dem.uc.pt (M.A. Neto), ana.amaro@dem.uc.pt (A.M. Amaro), calcobia@isec.pt (C.J. Alcobia), maria.paulino@uc.pt (M.F. Paulino).

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The effects of WBV on the human body have been widely investigated. An interesting evidence suggests that exposure to WBV in the upright position may be a useful intervention to increase bone mineral density, muscle strength and athletic performance as well as improve balance (Rehn et al., 2007, 2008; Mani et al., 2010). Conversely, occupational WBV in the sitting position has also been linked to low back pain (LBP), altered peripheral nervous system function, visual and vestibular disturbances, as well as prostate and gastrointestinal problems (Mani et al., 2010). The symptoms of exposure to HAV can be classified as vascular, neurological, or musculoskeletal (López-Alonso et al., 2013). Vascular symptoms can be classified under the heading of "Vibration White Finger", a phenomenon characterized by the whitening of fingers when exposed to low temperatures, while the most common neurological disorders are numbness and tingling in the fingers. The musculoskeletal damage associated with hand-arm vibration manifests, itself, in the form of pain at the upper extremities, with loss of manual sensitivity and dexterity (Rui et al., 2008), more recent studies also point to the appearance of Carpian tunnel syndrome (House et al., 2009). According to Friden (2001), the exposure to HAV can cause a variety of vascular and neuromuscular symptoms, like tingling in digits, discomfort or inflammation in the wrist and hand, digital lightening, cold intolerance, feebleness of the finger flexors or basic muscles and discoloration and trophic skin lesions of the fingers. However, Gerhardsson and Hagberg (2014) say that these symptoms depend on several factors, namely on the intensity and duration of exposure to the vibration, on the type of processes involved and on the tools used. Although these studies have been used for the purpose of quantifying the human exposure effects to HAV and to WBV in work environments, their concepts can also be used to quantify the human exposure effects to HAV and to WBV in sport conditions.

The level of exposure of the human body to external vibrations can be calculated either by objective or subjective methods (López-Alonso et al., 2013). Generally, the subjective methods tend to overestimate the exposure time, whereas objective methods tend to increase the amount of associated risk. The most common subjective methods include interviews and questionnaires (Bovenzi, 2008; Bovenzi et al., 2002; McCallig et al., 2010). The most common objective method to surveilling the exposure of humans to external vibrations is the one-site observation of work processes. In fact, this method was used in an important study carried out by the European Agency for Safety and Health at work (EASHT).

Regarding the measurement of vibration transmissibility to the human body, international standards have been developed over the years, in order to guide and enable uniform experimental methodologies that can obtain plausible results and encourage follow-up research in this area. In the literature, the majority of studies for the assessment of the mechanical vibration effects on the human body were performed according to the International Standard ISO 2631 (Sezgin and Arslan, 2012; Mechanical vibration, 1997; Madakashira-Pranesh, 2011), whereas for the assessment of the mechanical vibration effects on the hand-arm system were performed according to the calculation method outlined in the ISO 5349-1 (López-Alonso et al., 2013; Mechanical vibrations, 2001; Mechanical vibration, 2002; Knez et al., 2013). Because, in the European Union, one of every four workers claims to be exposed to vibration for up 2 h of his/her working day, the majority of the published studies are related with the work in specific heavy industry, namely agriculture vehicles, industrial trucks, hand-held tools in construction works and all-terrain vehicles (Sezgin and Arslan, 2012; López-Alonso et al., 2013; Solecki, 2007; Waters et al., 2008; Rehn et al., 2002). Nevertheless, although the WBV during training sport has been shown having some beneficial effects, including improvements in isometric/dynamic leg muscle strength, bone mineral density, back pain, health-related quality of life and decreased fall risk (Roelants et al., 2004; Abercromby et al., 2007; Tapp and Signorile, 2014), for extreme sport trainings a special care must be placed at whole-body and hand-arm vibrations daily limits.

In considering WBV, human response involves five separate effects: degraded comfort, interference with activities, impaired health, perception of low-magnitude vibration (as in buildings), and motion sickness (Griffin, 1990). Specific to the task investigated in this study, the effect assessed was the health.

The purpose of this study was to quantify the exposure to HAV and to WBV of a cross motorcycle driver when training in an endure-cross road and in a stone road. Moreover, an analysis on road cycling domains with segments of mountain biking, on track cycling and on the training of athletes in rollers was also conducted.

2. Material and methods

This research study applied the calculation method outlined in the International Standard (ISO) 5349, for the case of HAV, and in the ISO 2631, for the WBV (see section 2.2).

The vibration exposure levels of a common 200 cc cross motorcycle were evaluated based on the data collected from a motorcycle with a power of 28 kW conducted in endure-cross training. The tests were performed at two road scenarios: an off road facility used for endure motorcycle training in Portugal and a stone road, which is somewhat typical in Portugal. The data were collected from three tests at each road scenario, with an average velocity of 40 km/h.

The vibration exposure level from the bicycles were performed using two different bikes: a road bike with a frame in hard carbon and a track bike, used in track cycling competition. The road bike was evaluated at three road scenarios: asphalt; paved, which is similar to single tracks used in mountain biking, and a stone road pavement. The track bike was evaluated in a velodrome and in a training roller. Unlike road bikes, the track bikes have a fixed-gear and are optimized for racing at a velodrome. Thus, they have only a single gear and neither have freewheel nor brakes. The tests in the velodrome have been made by volunteers from the Portuguese national cycling team and were performed in the accredited by the UCI (Union Cycliste Internationale) Portuguese velodrome (Sangalhos), which has wooden floors with a 42° curve and a straight with 12°.

The motorcycle was driven by a sport professional male driver volunteer with 24 years and 73 kg of mass. The six volunteers recruited for the bike study have: age 15–18 years; height 170.3 ± 7.6 cm; mass: 59.9 ± 4.7 kg.

2.1. Calculation of vibration exposure

European Directive 2002/44/EC defines the following terms related with HAV and WBV received by workers. In this study, both concepts were adapted to drivers (moto and bike):

- **Hand-arm vibration**: the mechanical vibration that, when is transmitted to the hand-arm, entails risks to the health and safety of workers, in particular vascular disorders, osteo-articular injuries, and neurological or muscular disorders.
- **Whole-body vibration**: the mechanical vibration that, when is transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine.
- **Daily exposure action value**: the vibration exposure value that, if exceeded, calls for the implementation of a program of technical and/or organizational measures intended to reduce