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Ergonomic analysis of the effects of a telehandler's active suspended cab on whole body vibration level and operator comfort

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A R T I C L E I N F O

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A B S T R A C T

Introduction: Exposure to whole body vibration (WBV) is one of the most important risks for musculoskeletal disorders (MSDs). The objective of the study was to investigate whether an active cab suspension system fitted on a telehandler was effective in reducing WBV and in improving comfort.
Method: Sixteen male healthy professional operators drove a telehandler on a 100 m ISO 5008 smooth track at two different speeds (5 and 12 kph) with activated and deactivated cab suspension system. Adopting an ergonomic approach, different aspects of the human-machine interaction were analyzed: 1) vibration transmissibility, 2) subjective ratings of general comfort and local body discomfort, and 3) anthropometric characteristics of the users.
Results: A series of ANCOVAs showed that the suspension system was effective in reducing WBV at both speeds but did not affect the perception of comfort by the operators. Moreover, individuals with higher Body Mass Index (BMI) experienced more comfort. Some neck/shoulder and lumbar complaints and perceived hard jolts seemed to remain even when the system was activated. No correlations were found between objective and subjective measures.
Practical applications: Results suggest that the operators, given their wide range of physical variability, may need more adjustable or customizable WBV reduction systems.

1. Introduction

1.1. Background and motivation

Exposure to whole body vibration (WBV) has been identified as one of the most important risks for musculoskeletal disorders (MSDs) (Lyons, 2002; Osborne et al., 2012), having severe effects on low-back pain, neck-shoulder disorders, early degeneration of the spine and herniated discs (Bovenzi and Zadini, 1992; Griffin, 1990; Kittusamy and Buchholz, 2004). MSDs are a main issue of concern in agricultural industry: in the United States, a 2008 report showed that about 20 percent of farm workers suffer from musculoskeletal injuries (Kandel, 2008). In Europe, 2,070,000 out of over 40 millions occupational diseases among agricultural operators are MSDs (EU OSHA, 2010). Agricultural and earth-moving machinery operators are particularly at risk because they are usually exposed to vehicle vibrations for a long time (Mayton et al., 2008): indeed they typically spend many hours on the machine (Lin, 2011) and they have to accomplish many operations on different types of uneven terrain (Wikström, 1993), with the vehicle moving at various forward speeds (Lines et al., 1995; Scarlett et al., 2007).

The awareness of the risks related to WBV exposure led to the development of standards and requirements to maintain healthy working conditions. The development of WBV standards started in 1966 in Europe, resulting in the publication of ISO 2631 (Paschold and Sergeev, 2009). This standard is included into the European Commission Directive 2002/44/EC as a framework to measure, with the appropriate frequency weightings, the daily WBV exposure. The Directive imposes, on the European Union countries, duties on employers to protect employees who may be exposed to WBV vibration at work, and other persons who might be affected by the vibrations, whether they are at work or not. A partially different situation exists in the United States, where the WBV exposure limits are based upon the ISO 2631 standard but are voluntary (Paschold and Sergeev, 2009).

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In order to comply with rules and standards and to promote operators' health, safety and comfort, many technological and design innovations have been introduced on vehicles by manufacturers during last decades (for a review, see Donati, 2002 and Tiemessen et al., 2007). Innovations range from suspended seats (Hostens et al., 2004) to correct ergonomic layout of vehicle interior (Pope et al., 1998) and to cab suspension systems (Velmurugan et al., 2012). Concerning cab suspension, different solutions have been developed, from passive systems to more recent semi-active and active ones (Fischer and Isermann, 2004): active systems in particular represent an important innovation, not only for WBV control but also for the improvement of ride quality, handling and performance under different operating conditions (Ikenaga et al., 2000; Wong, 2001).

The effects of passive and semi-active cab suspension systems on WBV exposure have been investigated on many vehicles: agricultural tractors (Scarlett et al., 2007), fork lift trucks (Lemerle et al., 2002) and harvesters (Deprez et al., 2005). Less is known about active systems, and in particular with regard to telescopic handlers (telehandlers). These vehicles are indeed little investigated (Mansfield et al., 2009; Strambi et al., 2012) and not typically involved in user trials assessing WBV exposure, despite the fact that the telehandler is a versatile and widespread vehicle used on different off-road applications (construction, agriculture, mining, etc.) on uneven terrains and for a large number of different operations (Bertani, 2014).

Studies evaluating the effectiveness of suspension systems typically adopt an objective/mechanical approach, focusing in particular on acceleration and frequency analysis to determine workers' exposure limit and action values stated by rules and standards (De Temmerman et al., 2005; Hansson, 1995). Nonetheless, current sales trends show that the operator's comfort is becoming more and more important in determining the market value of agricultural machines (Vink, 2005). Previously, customers wished that their basic needs would be fulfilled at an affordable cost, while, in recent years, customers' decision to purchase a machine has become increasingly influenced by comfort (Cavallo et al., 2014a; Krause and Bronkhorst, 2003). Furthermore, comfort is one of the technological trajectories adopted by off-road vehicle manufacturers to develop their products (Cavallo et al., 2014b, 2015).

Many previous studies showed that is not always possible to predict comfort from objective methods only (De Looze et al., 2003; Mehta and Tewari, 2000). Nonetheless, and even though comfort is a subjective phenomenon (De Looze et al., 2003), users' perceptions are often left in the background. Only recently, researchers have become more aware of the positive outcomes that could be achieved by involving final users in the evaluation of comfort (Blüthner et al., 2008).

The role played by some anthropometric characteristics, such as stature, body mass and Body Mass Index (BMI), of the users of different vehicles in affecting WBV exposure and MSDs development has been investigated in previous studies but contrasting results are reported (Blood et al., 2010; Costa and Arezes, 2009; Mani et al., 2011; Milosavljevic et al., 2011, 2012; Sadeghi et al., 2012). Among these characteristics, the BMI is used by the World Health Organization to classify underweight, overweight and obesity in adults (WHO, 2000). Thus, it is a relevant index to be considered, because of the increasing rate of overweight and obesity conditions in the developed countries (WHO, 2000, 2004). Moreover, as an index calculated as the body mass in kilograms divided by the square of the stature in meters (kg/m^2), it is a combination of measurements. It is therefore essential for the interpretation of measurements, since, as reported by WHO (1995), body mass alone has no meaning unless it is related to an individual's stature. However, the relation between BMI and exposure to vibration is controversial: some studies pointed out that MSDs related to WBV exposure increase when the BMI raises (Bovenzi et al., 2006). On the opposite, results from other studies showed that vibrational discomfort decreases (Leino et al., 2006) and energy absorption increases (Wang et al., 2006) when the BMI raises.

Little is known, however, about the influence of this anthropometric characteristic on the perception of comfort in field machinery operators, whose population is undergoing the same trend of increasing overweight and obesity conditions as the general population (WHO, 2004).

1.2. Aims of the study

The objective of the present study was to investigate whether an active cab suspension system fitted on a telehandler was effective in reducing WBV and in improving comfort for the operators. The study adopted an ergonomic approach “*concerned with the understanding of the interactions among humans and other elements of a system […]*”, which considers users' involvement essential “*in order to optimize human well-being and overall system performance*” (International Ergonomics Association, 2015; see also Karwowski, 2006). The importance of this approach is highlighted also by the European Directive 42/2006 (European Commission, 2006), which states that “*Under the intended conditions of use, the discomfort, fatigue and physical and psychological stress faced by the operator must be reduced to the minimum possible, taking into account ergonomic principles such as: allowing for the variability of the operator's physical dimensions, strength and stamina; providing enough space for movements of the parts of the operator's body; avoiding a machine-determined work rate; avoiding monitoring that requires lengthy concentration; adapting the man/machinery interface to the foreseeable characteristics of the operators.*” (Annex 1, p.21). Thus, the study was addressed to assess not only the objective effects of the suspension system on vibration transmissibility but also the benefits perceived by the users, considered in their anthropometric variability.

To characterize the effects of the cab suspension system fitted on the telehandler the following aspects of the human-machine interaction were analyzed: 1) objective measures of vibration transmissibility, 2) subjective ratings of general comfort and local body discomfort, and 3) anthropometric characteristics of the users.

This study brings an additional contribution to the existing literature about WBV reduction and comfort improvement. First of all, the study investigates WBV exposure and vibrational comfort on an understudied type of field vehicle, the telescopic handler. Moreover, the vehicle was equipped with an active hydro-pneumatic suspension system. Additionally, the present research includes a subjective assessment of vibrational comfort and, finally, relations between objective measures, subjective evaluation and anthropometrics characteristics of the users are analyzed.

2. Materials and methods

2.1. Participants

Sixteen male healthy professional telehandler drivers took part in the study. Individuals with a minimum of 5 years of driving experience on telehandlers (driving-experience cut-off as in Kumar et al., 2001) were chosen to participate in the study. The mean age and experience operating telehandlers were 39.4 years (SD = 12.2; range 18–60) and 20.0 years (SD = 14.49; range 10–50), respectively. The participants completed a brief questionnaire about their