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Whole-body vibration and ergonomic study of US railroad locomotives

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Abstract

US locomotive operators have exposure to multi-axis whole-body vibration (WBV) and shocks while seated. This study assessed operator-related and ergonomic seating design factors that may have confounding or mitigating influence on WBV exposure and its effects. Vibration exposure was measured according to international guidelines (ISO 2631-1; 1997); ergonomic work place factors and vibration effects were studied with a cross-sectional survey instrument distributed to a randomly selected group of railroad engineers ($n = 2546$) and a control group; and during vehicle inspections. The survey response rate was 47% for the RR engineers ($n = 1195$) and 41% for the controls ($n = 323$). Results of the mean basic vibration measurements were for the x, y, z-direction and vector sum 0.14, 0.22, 0.28 and 0.49 m/s^2 respectively; almost all crest factors (CF), MTVV and VDV values were above the critical ratios given in ISO 2631-1. The prevalence of serious neck and lower back disorders among locomotive engineers was found to be nearly double that of the sedentary control group without such exposure. Railroad engineers rated their seats mostly unacceptable regarding different adjustment and comfort aspects (3.02–3.51; scale 1 = excellent to 4 = unacceptable), while the control group rated their chairs more favorably (1.96–3.44). Existing cab and seat design in locomotives can result in prolonged forced awkward spinal posture of the operator combined with WBV exposure. In a logistic regression analysis, time at work being bothered by vibration (h/day) was significantly associated with an increased risk of low back pain, shoulder and neck pain, and sciatic pain among railroad engineers. Customized vibration attenuation seats and improved cab design of the locomotive controls should be further investigated.

1. Introduction

In the European Union the risk of excessive whole-body vibration (WBV) exposure has been recognized and specific requirements regarding WBV exposure prevention have been introduced [1]. However, there is a paucity of information about the WBV exposure and working conditions of locomotive engineers in the generally available vibration and occupational health literature. One of the reasons is that this industry has been very reluctant in the past to study such issues and provide access to the work place. It appears that

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locomotive engineers and conductors are working in a unique environment with likely exposure to significant WBV and shocks depending on locomotive design, train speeds, and operational tasks [2,3]. In a recent epidemiological study of active North-American railroad (RR) engineers, the prevalence of serious type neck and lower back disorders was found to be nearly double that of a sedentary control group without such exposure [4], although the basic vibration levels appear to be lower compared to some road and off-road vehicles with high vibrations levels and back disorder risks. Ergonomic and seating conditions are important and possible modifying factors in an overall risk assessment of WBV exposure [5,6] and for musculoskeletal health in occupational medicine [7]. The goal of this study was the description and evaluation of cab and seating conditions in US built locomotives, including the subjective rating of seats and vibration effects by the locomotive engineers. Furthermore, the operational tasks that may be important and modifying factors in the risk assessment of WBV and prevention are reviewed.

2. Method

A self-administered 200-item standardized survey instrument was used to assess vibration effects, seating conditions and musculoskeletal disorders among a randomly selected subset of active US-American and Canadian RR engineers ($n = 2546$; out of total of 38,208) and a sedentary comparison group without rail-bound vehicle vibration exposure (New York State employed civil engineers, $n = 798$). The questionnaire was compiled from previously used and validated questions including the 'Standardized Nordic Questionnaire for the analysis of musculoskeletal symptoms', the British vibration exposure questionnaire developed by the Palmer and Griffin Group, University of Southampton and the Mount Sinai School of Medicine vibration survey [8–10]. The survey response rate was 47% for the RR engineers ($n = 1195$) and 41% for the controls ($n = 323$). The data was analyzed using SPSS statistical software (version 12.0, SPSS, Inc., Chicago, IL, September 2003). The association between the measures of exposure (vibration) and the measures of musculoskeletal pain (neck, lower back and sciatica pain) were tested by unconditional logistic regression. In addition, WBV was measured according to ISO 2631-1 (1997) in revenue-service locomotives ($n = 51$) during normal work-shifts. The seating conditions of a variety of in-service locomotives from different RR companies throughout the US RR system were inspected and typical operational tasks and body movements of locomotive operators were assessed by a trained medical observer.

3. Results

The results of the mean basic vibration measurements were for the x, y, z-direction and vector sum 0.14, 0.22, 0.28 and 0.49 m/s^2, respectively, based on full-shift WBV measurements ($n = 51$; duration approximately 4–16 h) of locomotives in revenue service in the US. The calculated SEAT ratios (seat/floor transfer function) indicated that the currently used seats did for the most part not reduce, but rather magnified the floor input vibration, particularly in the horizontal directions. Almost all of the calculated crest factor (CF), MTVV and VDV values were above the critical ratios given in ISO 2631-1, which suggests that relatively high and frequent irregular shocks on the seat level are common throughout routine work cycles (Table 1). The frequency resonance ranges of the measured locomotive seats were near the resonance range where the human spine shows the highest sensitivity (1–10 Hz).

The results of the survey showed that 75% of the RR engineers experienced "back pain" lasting more than 1 day in the year prior to completion of the survey, compared to 41% of the controls (Crude odds ratio (OR) = 4.32, 95% confidence interval (CI) 3.31–5.64). After statistical adjustment for demographic factors and non-job related vibration exposure, the adjusted OR remained essentially unchanged, 4.24 (95% CI 3.20–5.62). The adjusted OR for the occurrence of "sciatic pain" (a nerve root involvement) in engineers was 2.17 (95% CI 1.33–3.56). Other measures of back pain severity as well as neck and shoulder pain were also elevated among RR engineers. Within the RR group, higher job seniority was associated with a higher risk for persistent back pain.

Although the majority of currently used seats seem to have a back and foot support available (78–82%), there appears to be a lack of individual adjustment features, foot support (bracing device) and air cushioning devices (Table 2). In the survey, almost 2/3 of the engineers ($n = 1019$) complained about particular seat and