Abstract

Chronic exposure to whole-body vibration (WBV) represents a significant occupational hazard for shuttle car operators in underground coal mines. Exposure to high-magnitude, multiple-shock vibration events substantially increase the risk of work-related musculoskeletal disorders (WRMSDs), particularly in the lumbar region. Existing biomechanical models have struggled to adequately represent the nonlinear, complex vibration transmission across body segments, and few have integrated real-world epidemiological evidence into predictive frameworks for risk assessment. This thesis addresses these gaps by establishing a comprehensive framework that integrates low-cost instrumentation, biodynamic modeling, machine learning prediction, and field-based epidemiological validation. A novel Arduino-based, multi-channel vibration monitoring system employing ADXL345 triaxial accelerometers was developed to capture multi-segmental WBV exposure of shuttle car operators in real operational mining environments. The acquired dataset was used to construct machine learning-driven biodynamic models capable of predicting vibration transmission at different body segments while accounting for vibration frequency, anthropometric characteristics, posture, and seat-pelvis interface conditions. To forecast WRMSDs prevalence associated with WBV exposure, seven supervised machine learning classifiers were evaluated using data collected from 56 shuttle car operators. Input parameters included Standard Nordic Musculoskeletal Questionnaire (SNMQ) outcomes, demographic and ergonomic variables (age, BMI, experience, REBA score), and daily WBV exposure indices (A(8), VDV(8)). Among all models, the artificial neural network (ANN) achieved superior predictive performance (100% recall, AUC-ROC = 0.9688), ensuring robust identification of high-risk operators. Risk evaluation based on ISO 2631-1:1997 and EU Directive 2002/44/EC revealed that 82% of operators exceeded A(8) exposure action values and 70% exceeded VDV(8) thresholds. VDV(8) demonstrated greater sensitivity as a predictor of health risk than A(8). The predictive model showed a 40% prevalence of WRMSDs, closely matching the 38% observed epidemiological findings, thus confirming its real-world applicability. This thesis develops low-cost WBV monitoring and ANN-based biodynamic models, constructs a machine learning framework for WRMSDs prediction, and validates outcomes with epidemiological evidence, offering a robust, data-driven approach to occupational health risk management in high-vibration mining.

Keywords: Whole-body vibration, shuttle car operators, musculoskeletal disorders, vibration transmissibility, predictive modelling, machine learning.