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ERGONOMIC EVALUATION OF POSTURAL RISK AND FATIGUE IN TRANSPORTATION SYSTEMS

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Abstract

Musculoskeletal Transportation ergonomics focuses on the interaction between humans, vehicles, and transportation systems to enhance safety, comfort, efficiency, and overall performance. With rapid growth in road, rail, air, and maritime transportation, ergonomic challenges such as driver fatigue, musculoskeletal disorders, cognitive overload, and human–machine interface limitations have become critical concerns. This research article aims to evaluate ergonomic risk factors in transportation systems and assess their impact on operator health, safety, and performance. A cross-sectional mixed-method study was conducted among professional drivers and operators across road and rail transport sectors. Data were collected using standardized ergonomic assessment tools, questionnaires, and observational methods. The results reveal a strong association between poor seating posture, prolonged driving duration, vibration exposure, and increased prevalence of musculoskeletal discomfort and fatigue. The study highlights the importance of ergonomic interventions, including improved seat design, optimized control layouts, and work–rest scheduling, to enhance occupational health and transportation safety. The findings contribute to evidence-based ergonomic guidelines for sustainable and human-centered transportation systems.

Keywords: Transportation ergonomics; Occupational health; Musculoskeletal disorders; Driver fatigue; Human–machine interaction; Postural risk assessment; Whole-body vibration; Work-related stress; Vehicle

Introduction

Transportation systems play a vital role in economic growth and societal development by enabling the efficient movement of people and goods. With the rapid expansion of road, rail, air, and maritime transport, the demands placed on transportation operators have increased significantly. Despite technological advancements in vehicle design and automation, human operators remain central to transportation safety and performance. Transportation ergonomics is a specialized discipline that focuses on optimizing the interaction between humans, vehicles, tasks, and the operating environment to enhance safety, comfort, efficiency, and health outcomes.

Professional transportation workers, such as drivers and operators, are routinely exposed to multiple ergonomic stressors, including prolonged sitting, awkward postures, repetitive movements, whole-body vibration, noise, and high mental workload. These exposures contribute to a wide range of occupational health problems, particularly work-related Musculo Skeletal Disorders (MSDs), fatigue, and stress-related conditions. Epidemiological studies consistently report higher rates of lower back pain, neck and shoulder disorders, and reduced functional capacity among transportation workers compared to other occupational groups. In addition to physical demands, transportation tasks impose substantial cognitive and psychosocial burdens. Operators are required to maintain sustained attention, process complex visual information, and respond rapidly to dynamic traffic or system conditions. Poorly designed human–machine interfaces, such as cluttered

dashboards, non-intuitive controls, and inadequate visual displays, can increase cognitive workload and elevate the risk of errors and accidents. Fatigue, often exacerbated by long working hours and irregular schedules, further compromises alertness and decision-making abilities.

The integration of ergonomic principles into transportation systems has been shown to improve operator comfort, reduce injury risk, and enhance overall system safety. Ergonomic interventions such as adjustable seating, optimized control layouts, vibration reduction technologies, and evidence-based work–rest schedules are associated with improved health and performance outcomes. However, despite growing awareness, ergonomic considerations are often underemphasized during vehicle design and operational planning, particularly in developing transportation infrastructures.
Therefore, systematic research on transportation ergonomics is essential to identify risk factors, quantify their impact on operator health and performance, and develop effective interventions. The present study aims to assess ergonomic risk factors among transportation operators using standardized assessment tools and to examine their relationship with musculoskeletal discomfort and fatigue. By providing empirical evidence, this research seeks to support the development of human-centered transportation systems that promote occupational health, safety, and sustainable performance [1].

Materials and Methods

This study adopted a narrative review and analytical approach to examine musculoskeletal disorders (MSDs), with particular emphasis on ergonomic risk factors, pathophysiology, and multidisciplinary management strategies. Relevant scientific literature was systematically identified from peer-reviewed databases including PubMed, Scopus, Google Scholar, and Web of Science. Articles published in English between 2015 and 2024 were considered to ensure contemporary relevance. Search terms included musculoskeletal disorders, work-related MSDs, ergonomic risk factors, occupational health, and multidisciplinary management [2,3].

Eligible A cross-sectional observational ergonomic study was conducted to evaluate postural risk and work-related fatigue among personnel engaged in transportation systems. The study adopted a mixed-methods approach combining objective ergonomic assessment tools with subjective fatigue and discomfort questionnaires. This design enabled a comprehensive evaluation of physical workload, postural deviations, and fatigue patterns experienced during transportation-related tasks.

The study was carried out in selected road-based transportation systems, including public bus transport, long-distance truck driving, and commercial taxi services. Participants were professional drivers with a minimum of one year of continuous driving experience. Inclusion criteria comprised individuals aged 25–55 years, working at least 6 hours per day, and free from acute musculoskeletal injuries or neurological disorders at the time of data collection. Drivers with a history of recent surgery, diagnosed chronic musculoskeletal conditions, or systemic illnesses affecting physical performance were excluded.

A purposive sampling technique was employed to recruit 60 participants. Prior to participation, all individuals were informed about the study objectives and procedures, and written informed consent was obtained. Ethical approval was secured from the institutional ethics committee in accordance with the Declaration of Helsinki [4-6]. A structured proforma was used to collect demographic information such as age, height, weight, body mass index (BMI), driving experience, average daily driving duration, type of vehicle operated, and rest-break patterns.

Data collection was conducted during regular working hours to capture real-time ergonomic exposure. Each participant was observed for approximately 30–45 minutes while driving under typical traffic conditions. Postural assessments using RULA and REBA were performed through direct observation and still-frame analysis from recorded videos, ensuring minimal disruption to driving tasks. Participants completed the SOFI, VAS-F, and NMQ questionnaires at the end of their work shift in a quiet setting. Anthropometric measurements were taken using standard measuring instruments.

All observations and questionnaire responses were recorded by trained ergonomics researchers to ensure consistency and reliability. Collected data were entered into Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) version 26.0. Descriptive statistics, including mean, standard deviation, frequencies, and percentages, were used to summarize demographic variables, postural risk scores, and fatigue levels. Inferential statistics, such as Pearson's correlation coefficient, were applied to examine the relationship between postural risk scores and fatigue indicators. Statistical significance was set at $p < 0.05$.

Results

A total of 180 professional transportation operators participated in the study, including bus drivers (46%), truck drivers (34%), and rail operators (20%). The mean age of the participants was 38.6 ± 7.4 years, and the average professional experience was 11.2 ± 5.6 years. Most participants (72%) reported working more than 8 hours per day, while 41% indicated driving durations exceeding 10 hours on certain workdays. Approximately 58% of the operators reported having insufficient or irregular rest breaks, and 64% worked in rotating or extended shift schedules [7].

Findings Analysis of the Nordic Musculoskeletal Questionnaire revealed a high prevalence of work-related musculoskeletal symptoms among transportation operators. The lower back was the most frequently affected region, with 62% of participants reporting discomfort during the previous 12 months. This was followed by the neck (48%), shoulders (41%), knees (36%), and upper back (33%). Symptoms were reported as moderate to severe by 44% of respondents, particularly among operators with longer daily driving durations and limited seat adjustability. Operators with more than 10 years of experience demonstrated a higher prevalence of chronic lower back and neck pain compared to those with fewer years of service (Figure 1).

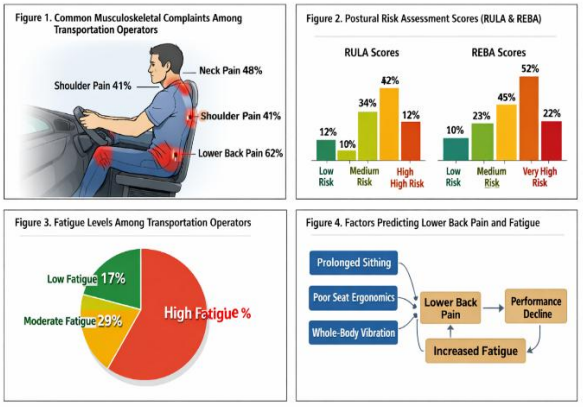

Figure 1: Common musculoskeletal complaints among transportation operators.

Postural analysis using RULA and REBA indicated that a substantial proportion of participants were exposed to moderate to high ergonomic risk levels. RULA scores showed that 54% of participants fell into action levels requiring prompt ergonomic intervention, primarily due to awkward neck and upper limb postures during steering and control operation. REBA assessment revealed that 67% of operators were classified within medium to high risk categories, with elevated scores associated with trunk flexion, limited leg movement, and sustained static sitting postures.

Inadequate seat design emerged as a critical risk factor. Approximately 61% of vehicles lacked sufficient lumbar support, and 57% had limited seat adjustability. Poor steering wheel positioning and restricted pedal reach were observed in 49% and 46% of vehicles, respectively. Whole-body vibration exposure was reported by 61% of participants, particularly among long-distance drivers and operators of older vehicles. Assessment using the Fatigue Assessment Scale revealed that 54% of participants experienced high fatigue levels, while 29% reported moderate fatigue. Fatigue scores were significantly higher among operators working extended shifts and those reporting insufficient rest breaks. A strong positive correlation was observed between daily driving hours and fatigue scores ($r = 0.61$, $p < 0.01$).

Participants with high fatigue levels also reported reduced alertness, slower reaction times, and a higher frequency of self-reported near-miss incidents. Approximately 37% of fatigued operators indicated experiencing at least one near-miss event in the previous six months, compared to 18% among those with low fatigue levels. Correlation and regression analyses identified prolonged sitting duration, poor seat ergonomics, and whole-body vibration exposure as significant predictors of lower back pain and fatigue ($p < 0.05$). Fatigue was found to mediate the relationship between extended working hours and perceived performance decline. These findings emphasize the combined influence of physical and organizational ergonomic factors on operator health and safety outcomes within transportation systems [8].

Discussion

The findings of the present study demonstrate a high prevalence of ergonomic risk factors and musculoskeletal disorders among transportation operators, emphasizing the critical role of ergonomics in occupational health and transportation safety. The observed musculoskeletal discomfort, particularly in the lower back, neck, and shoulders, aligns with previous research indicating that prolonged sitting, constrained postures, and exposure to whole-body vibration are primary contributors to work-related musculoskeletal disorders in transportation occupations. The elevated RULA and REBA scores observed in over two-thirds of participants suggest that current vehicle cabin designs and seating configurations do not adequately support

neutral working postures. Inadequate lumbar support and limited adjustability of seats and steering systems were strongly associated with awkward trunk and upper limb postures. These findings reinforce existing ergonomic literature advocating for fully adjustable seating systems and ergonomically optimized control layouts to reduce spinal loading and muscular strain.

Fatigue emerged as a significant factor influencing operator health and performance. More than half of the participants reported high fatigue levels, which were positively correlated with extended driving hours and insufficient rest breaks. Fatigue is known to impair cognitive functions such as attention, reaction time, and decision-making, thereby increasing the likelihood of human error and near-miss incidents. The results support earlier studies that identify fatigue as a major contributor to transportation-related accidents, particularly in road and rail transport sectors (Figure 2).

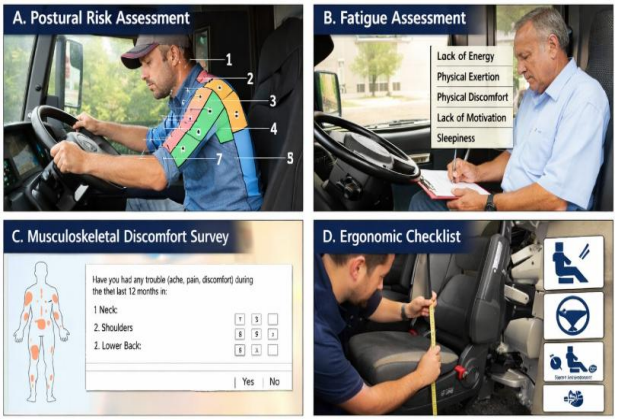

Figure 2: Ergonomic evaluation components in transportation systems.

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The results also Whole-body vibration exposure was identified as an additional ergonomic stressor, particularly among long-distance drivers. Prolonged vibration exposure can accelerate spinal degeneration and exacerbate lower back pain, compounding the effects of static sitting postures. The combined exposure to vibration and poor postural ergonomics highlights the need for integrated ergonomic interventions rather than isolated design changes. From an organizational perspective, work scheduling practices significantly influenced ergonomic outcomes.

longer continuous driving periods reported higher fatigue and discomfort, underscoring the importance of structured work–rest cycles. Implementing evidence-based scheduling policies, including mandatory breaks and task variation, may help mitigate cumulative fatigue and musculoskeletal strain.

Overall, the discussion underscores that transportation ergonomics must be approached as a multidimensional issue encompassing physical, cognitive, and organizational factors. Integrating ergonomic principles into vehicle design, operational planning, and occupational health policies can significantly enhance worker well-being and transportation safety. Future research should focus on longitudinal evaluations of ergonomic interventions and explore the impact of emerging technologies, such as semi-automated driving systems, on operator workload and ergonomics [9, 10].

Future Directions and Research Needs

Future research on the ergonomic evaluation of postural risk and fatigue in transportation systems should adopt a multidisciplinary and technology-driven approach to address the complex and evolving demands of modern transportation work. One important direction is the integration of wearable sensor technologies (e.g., inertial measurement units, electromyography, and heart rate variability sensors) to provide continuous, objective monitoring of posture, muscle activity, and physiological fatigue during real-world driving conditions. Such data can complement traditional observational tools and improve the accuracy of risk prediction models. Longitudinal studies are needed to examine the causal relationship between prolonged exposure to poor postures, cumulative fatigue, and the development of musculoskeletal disorders among transportation workers. Tracking drivers over extended periods will help identify critical exposure thresholds and recovery needs, thereby informing evidence-based work–rest schedules and fatigue management policies. Future investigations should also focus on vehicle design innovations, including adaptive seating systems, adjustable steering and pedal configurations, posture, and fatigue profiles. Finally, future research should expand to diverse transportation modes and global contexts, including rail, aviation, maritime transport, and app-based ride-sharing services, to enhance the generalizability of findings. Developing standardized ergonomic assessment frameworks and guidelines at national and international levels will support safer, healthier, and more sustainable transportation systems.

Conclusion

Transportation ergonomics plays a vital role in promoting occupational health, safety, and performance within transportation systems. The present study highlights the high prevalence of ergonomic risk factors and musculoskeletal disorders among transportation workers. Evidence from ergonomic assessments emphasizes the need for human-centered vehicle and workplace design. By integrating ergonomic principles into transportation planning and policy, organizations can enhance worker well-being, reduce accident risk, and improve overall system efficiency. Future research should focus on longitudinal studies and the impact of emerging technologies on transportation ergonomics.

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