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Recent Advancements in Ergonomic Risk Assessment: Integration of Artificial Intelligence, Wearable Technology, and Industry-Specific Approaches

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ABSTRACT

Ergonomic risk assessment is crucial in preventing work-related musculoskeletal disorders (WMSDs) across various industries. Traditional methods, while effective, have limitations, such as reliance on manual observations and a lack of real-time monitoring. Recent technological advancements, including artificial intelligence (AI), wearable sensors, and industry-specific solutions, are addressing these gaps. AI and machine learning techniques enable real-time data analysis, providing more accurate and proactive ergonomic assessments. Wearable technology, such as inertial measurement units and pressure sensors, offers continuous monitoring of worker movements and postures, helping to prevent injuries in sectors like healthcare, construction, and manufacturing. These tools also allow for personalized ergonomic interventions by assessing individual risk factors in real-time. Industry-specific approaches have also emerged, particularly in high-risk fields such as healthcare and mining, where the integration of ergonomic and psychosocial stressors provides a comprehensive risk assessment model. In addition to physical ergonomics, advancements now incorporate psychosocial factors, addressing issues like organizational culture and job stress, which significantly influence musculoskeletal health. Finally, technological innovations such as simulation and modeling tools further enhance ergonomic assessments by simulating worker movements and identifying high-risk postures. However, challenges remain in standardizing these tools and integrating them into existing workflows. The evolution of ergonomic risk assessments towards more automated, precise, and real-time systems promises to reduce WMSDs and improve overall workplace safety.

Keywords: Ergonomic risk assessment, Wearable technology, Artificial intelligence, Work-related musculoskeletal disorders (WMSDs), Real-time monitoring, Industry-specific ergonomics, Psychosocial factors

1. INTRODUCTION

Ergonomics plays a critical role in improving workplace safety and productivity by enhancing the interaction between workers and their tasks. Work-related musculoskeletal disorders (WMSDs) are a prevalent occupational health issue worldwide, responsible for significant financial and social burdens. Sectors such as healthcare, construction, manufacturing, and mining experience high incidences of WMSDs due to factors like awkward postures, repetitive motions, and physical strain. These disorders are the leading cause of injury, disability, and absenteeism across industries (Boocock et al., 2024; Sabino et al., 2024; Chen et al., 2024; Zhang et al., 2024).

Traditional ergonomic risk assessment methods have long been utilized to evaluate these workplace risks. Techniques like Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and the Ovako Working Posture Analysis System (OWAS) are widely used to determine the risk associated with specific tasks and postures (Kiraz & Geçici, 2024; Chen, 2024). These methods rely heavily on observational checklists and the expertise of ergonomists, offering a subjective perspective that can vary significantly between assessments. Although effective, these methods struggle to account for rapid or transient movements, particularly in dynamic industries such as construction and manufacturing (Chen, 2024).

The limitations of traditional methods—chiefly their reliance on manual observations—can lead to inconsistencies in outcomes. These approaches are often time-consuming and labor-intensive, making them less feasible in fast-paced or complex environments (Mazaheri et al., 2024; Khamaisi et al., 2024). In industries like construction and healthcare, where workers face significant WMSD risks, real-time monitoring is crucial for identifying and mitigating physical exposures (Chen et al., 2024; Sabino et al., 2024). Moreover, in industries like mining, ergonomic and psychosocial stressors add to the challenge, underscoring the need for more advanced tools to manage workers' musculoskeletal health (Zhang et al., 2024).

Recent advancements in technology offer promising solutions to the limitations of traditional ergonomic assessments. The integration of artificial intelligence (AI), machine learning, wearable sensors, and computer vision technologies provides more accurate, consistent, and efficient evaluations. These advancements enable real-time data collection and analysis, allowing for proactive interventions to prevent WMSDs. For instance, AI models can predict prolonged postures based on data from wearable sensors, enabling personalized risk assessments and health recommendations (Sen et al., 2024). Wearable devices, such as inertial measurement units and in-shoe plantar pressure systems, also provide valuable insights into the physical strain experienced by workers in real-world settings (Simon et al., 2024).

Technological innovations in ergonomic assessments, such as web-based platforms, facilitate ergonomic risk assessments through automated reports for established methods like REBA, RULA, and OWAS (Kiraz & Geçici, 2024). These systems improve consistency and usability in ergonomic evaluations, particularly in industries where real-time monitoring is critical. Additionally, specific tools have been developed to address industry-specific needs. In mining, for example, comprehensive models incorporating both ergonomic and psychosocial stressors help assess miners' risks of WMSDs (Zhang et al., 2024). In healthcare, tools like the TilThermometer are used to generate risk profiles based on physical exposure, especially for workers engaged in patient handling tasks (Wåhlin et al., 2024).

Including psychosocial factors in ergonomic assessments is crucial for addressing the comprehensive well-being of workers. Research has shown that factors like organizational support, job stress, and workplace culture significantly influence musculoskeletal health (Zhang et al., 2024). Addressing these factors alongside physical risk assessments ensures a more holistic approach to preventing WMSDs and improving workplace conditions.
Moreover, advancements in ergonomic standards and guidelines are essential to reflect the progress in technology and evolving industry demands. Studies comparing current methods with European Union standards have highlighted discrepancies in ergonomic risk criteria, emphasizing the need for uniform standards to ensure accurate and reliable assessments (Onofrejova et al., 2024). Updated guidelines that integrate technological innovations will better serve industries by providing more relevant, efficient, and accurate tools for assessing ergonomic risks.

2. TECHNOLOGICAL INNOVATIONS IN ERGONOMIC RISK

Technological advancements, particularly in artificial intelligence (AI) and machine learning (ML), have brought significant improvements to ergonomic risk assessment. These technologies have enhanced the capacity for handling extensive datasets, improving the prediction accuracy of potential risks and enabling more proactive measures to prevent work-related musculoskeletal disorders (MSDs). AI and ML applications in ergonomics span across multiple areas, including natural language processing (NLP) for risk analysis, uncertainty-aware models, automated posture assessment via computer vision, and real-time three-dimensional (3D) pose estimation. NLP has been employed in ergonomic assessments to automate the analysis of textual data concerning physical risks. Parikh et al. (2024) introduced a job improvement process that integrates deep learning-based NLP techniques for automatic root cause analysis and control recommendations. Their approach processed textual descriptions of work-related actions and objects, identifying causes of MSDs such as high shoulder forces due to small caster sizes. This method went beyond traditional assessments by providing actionable recommendations, like using larger diameter casters to reduce risks. The process significantly improved job efficiency by directly addressing ergonomic hazards rather than just generating risk scores.

Incorporating uncertainty in machine learning models is essential for making reliable predictions in ergonomic assessments. Sen et al. (2024) proposed ERG-AI, a machine learning pipeline that combines uncertainty-aware models with large language models (LLMs) to enhance ergonomic risk predictions. ERG-AI utilizes wearable sensors to predict worker postures and estimates the uncertainty of these predictions, adding a layer of confidence in its assessments. It generates personalized health risk evaluations and provides ergonomic recommendations via natural language prompts created with LLMs like GPT-4. This integration helps workers understand their risks and receive tailored feedback on how to mitigate them, addressing a key gap in current ergonomic risk assessments. The model was tested on the Digital Worker Goldicare dataset, demonstrating its effectiveness in delivering accurate predictions and valuable recommendations.

Computer vision has also been applied in ergonomic risk assessments to automate the analysis of postures and movements. Kiraz and Geçici (2024) developed a web-based platform that uses computer vision and machine learning to generate ergonomic risk reports based on methods like REBA, RULA, and OWAS. The platform employs the Region-based Convolutional Neural Network (R-CNN) from the MediaPipe library to detect body key points and joint angles from video footage, automating the evaluation process. This eliminates the need for manual input, ensuring consistent results and reducing the user's dependency on expertise. The platform showed an overall accuracy of 92% in detecting body key points, validating its reliability in assessing ergonomic risks.

Real-time 3D pose estimation has become a crucial tool for assessing ergonomic risks in complex and dynamic environments such as construction sites. Chen et al. (2024) developed a framework for real-time ergonomic risk assessment using a co-learning-powered 3D human pose estimation model. The model integrates 2D and 3D features from multidimensional datasets, enabling it to track workers' postures in real time. This approach facilitates timely interventions by identifying risky postures that may lead to MSDs, improving workplace safety by allowing proactive measures to mitigate potential risks.

2. WEARABLE TECHNOLOGY AND SENSOR INTEGRATION

Advancements in wearable technology and sensor integration have significantly enhanced ergonomic risk assessments across various sectors. These innovations offer cost-effective, continuous monitoring of workers' physical activities, enabling early detection and prevention of work-related musculoskeletal disorders (WMSDs). Recent developments include the creation of affordable sensors, their application in healthcare, and their use in agriculture to monitor ergonomic risks.

In industrial environments, particularly automotive manufacturing, the demand for ergonomic assessment tools that are both effective and affordable has risen. González-Alonso et al. (2024) introduced an innovative hardware-software pipeline to automate ergonomics assessment in workplaces. The system integrates custom-designed inertial measurement unit (IMU) sensors with real-time worker movement tools and inverse kinematics processing, generating Rapid Upper Limb Assessment (RULA) reports. By utilizing open-source platforms like Unity3D and OpenSim, the system avoids proprietary technologies, ensuring transparency and cost reduction. Tested in an automotive factory, the system showed high reliability, achieving a 0.95 cross-correlation and a root mean square error (RMSE) under 10 degrees for elbow joints and 12 degrees for shoulder joints compared to a gold standard system. With less than a 5% difference in RULA scores, the solution demonstrated accuracy in ergonomic risk assessments. This cost-effective solution has the potential to democratize the use of wearable technology for ergonomic analysis, potentially reducing musculoskeletal disorders and improving long-term worker health in various industrial settings.

Healthcare professionals are also exposed to multiple physical risk factors leading to WMSDs, which can negatively impact their well-being and job performance. Sabino et al. (2024) conducted a systematic review of wearable technology's application in ergonomic risk assessments among healthcare workers. The review, covering 29 studies, highlighted the growing interest in this area, with most studies published in the last three years. Inertial sensors were used to monitor awkward postures, while surface electromyography (sEMG) sensors tracked muscle activity during work tasks. Wearable technology was found to be reliable and non-invasive for continuous ergonomic monitoring. However, challenges such as device comfort, data privacy, and integration into daily workflows were noted. Further research is needed to expand the applicability of wearable devices for ergonomic interventions in healthcare, but the technology shows considerable promise in preventing WMSDs.

In the agricultural sector, workers frequently engage in tasks involving awkward postures and repetitive motions, increasing their risk of WMSDs. Cividino et al. (2024) addressed this issue by developing and evaluating new wearable sensors to monitor workers' postures in viticulture. Traditional methods of assessing working postures are often impractical in dynamic environments due to manual measurement limitations. The researchers created a low-cost, durable wearable device equipped with 3-axis accelerometers and a gyroscope to monitor the hand-wrist-forearm system. The sensor was tested in real-world scenarios such as vine pruning, successfully assessing postures and quantifying risk levels associated with the task. This technology effectively measures wrist angles and hand positions, enabling better evaluation of ergonomic risks in agriculture. The study concluded that wearable devices could address challenges such as high costs and limited adaptability, contributing to WMSD prevention in agricultural settings.

3. SIMULATION AND MODELING TOOLS

Advancements in simulation and modelling tools have greatly enhanced the precision and efficiency of ergonomic risk assessment. These tools provide the ability to simulate human postures and movements, enabling the identification and evaluation of work-related musculoskeletal disorder (WMSD) risks in various workplace settings.

One such development is the use of ergonomic evaluation software to analyze worker movements and postures. Chen (2024) utilized Jack simulation software to assess the postures of express couriers handling small parcels. As couriers frequently handle large volumes of deliveries under tight schedules, they are exposed to elevated risks of WMSDs. The study used SolidWorks to model parcels, carriages, and trucks, which were then imported into Jack software for ergonomic analysis. The digital human model simulated parcel handling at different heights and positions, identifying high-risk postures, particularly when reaching for parcels at the bottom or inner side of the carriage. The Ovako Working Posture Analysis System (OWAS) and Rapid Upper Limb Assessment (RULA) methods were employed to quantify the risks. The analysis found that significant ergonomic risks are present when handling parcels in difficult-to-reach positions, and proposed solutions such as installing doors on both sides of the carriage to reduce the strain on couriers. This study highlights how simulation tools like Jack provide an effective, low-cost alternative to traditional methods, offering quantitative insights into workplace ergonomics and aiding in designing safer workflows.

In addition to software-based evaluations, numerical simulations have become increasingly important in occupational health. Amiri et al. (2024) reviewed the application of numerical simulation tools in occupational health studies, categorizing hazards into several subgroups, including ergonomics. The study emphasized the utility of software like Fluent and k–ϵ turbulence models in assessing risks related to air pollution, ventilation, and other hazards. For ergonomic assessments, these simulation tools model human interactions with work environments, enabling a detailed evaluation of physical risks. Numerical simulations allow for precise analysis of workplace conditions, enhancing experts' ability to design interventions that mitigate occupational hazards. The review suggested broader adoption of such tools in occupational health, as they provide a more comprehensive understanding of the risks faced by workers in diverse industries.

Zhang et al. (2024) explored the use of advanced models in assessing safety performance and ergonomic risks in high-risk work environments, such as space teleoperation. They developed a hybrid fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to analyze multiple factors affecting safety performance in such operations. Through expert consultation and literature reviews, the study identified 16 key factors, including team communication, cognitive abilities, and control mode design, that significantly influence safety in teleoperation tasks. The hybrid fuzzy DEMATEL method effectively handled uncertainty and complexity, providing valuable insights into the relationships between these factors. This modeling approach underscores the importance of identifying critical ergonomic risk factors in environments where workers are exposed to complex, interrelated stressors. The application of fuzzy and mechanistic models in ergonomic risk assessment offers a way to evaluate these intricate factors and improve safety in challenging work settings.

4. INDUSTRY-SPECIFIC ERGONOMIC RISK ASSESSMENTS IN HEALTH SECTOR

The healthcare sector presents distinct challenges in ergonomic risk assessment due to the physical demands placed on professionals, particularly during patient handling. Recent advancements in this area have centered on improving guidelines, developing effective risk assessment tools, and integrating wearable technology to monitor physical load exposure.

Speth (2024) emphasizes the importance of updated guidelines provided by the Association of periOperative Registered Nurses (AORN) in addressing ergonomic risks. These guidelines aim to minimize injuries during patient handling in perioperative environments, which involve tasks like lifting and moving patients, activities that increase injury risks for both staff and patients. The guidelines promote the implementation of a Safe Patient Handling and Mobility (SPHM) program, which includes ergonomic facility design, SPHM technology use, and individualized plans for patient handling. The guidelines also recommend assessments of fall risk and mobility to ensure safety for patients and healthcare workers. By following these updated practices, perioperative professionals can reduce work-related musculoskeletal disorders (WMSDs) and improve overall safety in healthcare settings.

Effective risk profiling tools play a crucial role in identifying and mitigating ergonomic hazards. Wåhlin et al. (2024) conducted a feasibility study using the TilThermometer to assess physical exposure among healthcare workers engaged in patient handling and movement tasks. This study, involving 54 workers across 17 Swedish care units, demonstrated that the

TilThermometer could effectively identify high-risk activities, such as showering patients without adjustable seats or applying compression stockings without recommended assistive devices. The tool was found to be user-friendly, facilitating team discussions and providing a clear overview of patient workloads. However, some challenges were noted, such as difficulties in categorizing patients into mobility groups. Despite this, the TilThermometer was generally well-received, with average scores close to 4 on a 5-point scale, indicating its potential to contribute to safer patient handling practices by identifying specific ergonomic risks.

The integration of wearable technology in ergonomic risk assessments offers substantial advancements, particularly for real-time monitoring of physical load exposure. Sabino et al. (2024) reviewed 29 studies, mostly published within the last three years, exploring the application of wearable devices for assessing the ergonomic risks faced by healthcare workers. These devices primarily consisted of inertial sensors and surface electromyography (sEMG) sensors. Inertial sensors measured exposure to awkward postures by capturing motion data, while sEMG sensors assessed muscle activity related to physical exertion during work tasks. The review highlighted the strengths of wearable devices, such as their ability to provide objective, non-invasive, and continuous data, enhancing the accuracy of ergonomic assessments. However, challenges remain, including the need for further validation studies to ensure the effectiveness of wearable technology across different healthcare settings. The authors underscored the need for continued research to confirm the broader applicability of these technologies in preventing WMSDs through ergonomic interventions.

5. INDUSTRY-SPECIFIC ERGONOMIC RISK ASSESSMENTS IN CONSTRUCTION AND MANUAL LABOR

Industries such as construction, agriculture, and service centers face significant ergonomic challenges due to the physically demanding nature of the tasks involved. Recent advancements have aimed to address these issues through real-time ergonomic risk assessments, evaluations of manual handling tasks, and the assessment of pushing and pulling activities.

In the construction sector, ergonomic risks are prevalent due to the strenuous physical tasks and awkward postures that workers must adopt. Chen (2024) conducted an evaluation using Jack simulation software to assess the ergonomic risks faced by express couriers handling small parcels. By creating geometric models of parcels, express carriages, and delivery trucks, the study simulated typical parcel-handling tasks and employed tools such as the Ovako Working Posture Analysis System (OWAS) and Rapid Upper Limb Assessment (RULA). The findings highlighted that handling parcels at various heights and distances posed significant risks for work-related musculoskeletal disorders (WMSDs). Risk levels were particularly high when parcels were placed at the top or bottom of carriages, requiring workers to bend or stretch excessively. The study proposed practical interventions, such as installing doors on both sides of carriages to allow workers to maintain better postures and visual fields, potentially reducing the risk of injury.

In agriculture, the repetitive nature of manual tasks, such as separating cup lumps in rubber processing, poses a high risk for WMSDs. Varghese et al. (2024) conducted an ergonomic risk assessment using the Rapid Entire Body Assessment (REBA) method on 32 workers in Kerala, India. The study revealed that 84% of participants were at medium risk for developing musculoskeletal disorders, while 16% were at high risk, necessitating immediate ergonomic interventions. The primary causes of high REBA scores were repetitive work, sustained awkward postures, and excessive wrist twisting. The study recommended the use of ergonomically designed tools to minimize wrist flexion and twisting, thereby reducing WMSD risks and improving worker safety and productivity.

Mechanics in service centers, particularly those working in tire service centers, also face ergonomic risks from pushing and pulling tasks. Kamarudzaman et al. (2024) investigated the correlation between musculoskeletal symptoms and the ergonomic risks associated with these activities using the Risk Assessment of Pushing and Pulling (RAPP) tool and the Nordic Musculoskeletal Questionnaire (NMQ). The study, which surveyed 116 mechanics in Taiping, Perak, found that 75.86% of participants experienced musculoskeletal symptoms, with the most common complaints being low back pain (79.81%), shoulder pain (68.97%), and elbow pain (59.48%). The RAPP tool indicated that poor posture, demanding work patterns, and inadequate equipment contributed to medium risk levels for WMSDs. The study concluded that enhancing ergonomic awareness through education and training could help mechanics adopt better practices, thereby reducing the prevalence of musculoskeletal disorders and improving overall health and job performance.

6. INTEGRATION OF PSYCHOSOCIAL FACTORS

Recent advancements in ergonomic risk assessment have increasingly incorporated psychosocial factors, recognizing their significant impact on the development of work-related musculoskeletal disorders (WMSDs). Psychosocial stressors such as workplace culture, organizational justice, and violence have been identified as critical elements influencing worker safety and health. Studies across various industries have highlighted the importance of integrating ergonomic and psychosocial elements to develop comprehensive risk assessment models.

Zhang et al. (2024) developed a fuzzy Bayesian network model to assess the interaction between ergonomic and psychosocial stressors in frontline miners. The study identified factors such as vibration, awkward postures, inadequate organizational support, and a negative workplace culture as major contributors to the 79.7% probability of WMSDs among miners. This model serves as a decision-support tool, targeting both ergonomic and psychosocial stressors to improve musculoskeletal health in high-risk industries. Obeidat et al. (2024) also examined key factors affecting occupational injuries using data from the U.S. General Social Survey. They found that demographics, job characteristics, and organizational factors like management trust and coworker support significantly influenced injury rates. Enhancing communication and fostering a positive work culture were recommended as strategies to reduce these risks.

Participatory ergonomics, which involves workers directly in risk assessments, has been shown to improve workplace safety by promoting collaboration and empowerment. Jaffel et al. (2024) demonstrated the effectiveness of the DEPARIS participatory risk screening tool in a Tunisian garment manufacturing company. This approach fostered open dialogue among employees and led to the identification of critical ergonomic issues, particularly for machine operators. The inclusive nature of the DEPARIS tool allowed employees to contribute valuable insights, resulting in practical solutions and a culture of continuous improvement.

Workplace violence is another critical factor impacting ergonomic risk assessments. Magnavita et al. (2024) emphasized the need for accurate assessment of workplace violence to establish effective prevention strategies. They recommended a sequential risk management process involving risk identification, quantitative assessment, and impact evaluation. Supplementing spontaneous reports with systematic data collection through interviews and surveys can provide a clearer picture of the prevalence and impact of workplace violence. This method ensures that interventions are tailored to specific workplace needs and are based on robust evidence.

7. ADVANCEMENTS IN STANDARDS, GUIDELINES, AND METHODOLOGIES

Recent advancements in ergonomic risk assessment have led to significant improvements in standards, guidelines, and methodologies, ensuring that workplace design and processes are aligned with both safety and efficiency. Onofrejova et al. (2024) compared ergonomic risk assessment methods with European Union (EU) standards in Slovakia, focusing on their consistency with legislative requirements. Using the Captiv wireless sensory system to collect data on worker postures, the study found discrepancies among various standards, including Slovak Decree 542/2007 Coll., STN EN 1005-4+A1, and French standards. These differences in defining hazardous postures across different standards affected the evaluation of work-related musculoskeletal disorders (WMSDs). The study highlighted the need for uniform threshold values for body postures to ensure consistency and accuracy in ergonomic risk assessments, particularly for industrial workplaces across the EU.

In the realm of cognitive ergonomics, Gualtieri et al. (2024) explored the integration of human factors into the design of collaborative robotics, particularly relevant in the evolving landscape of Industry 5.0. This study systematically updated and validated design guidelines for cognitive ergonomics in human-robot interactions. By conducting extensive literature reviews and engaging with 108 experts through surveys, the researchers identified key aspects to improve operator well-being and safety when interacting with advanced manufacturing systems. The study emphasized the importance of inclusivity and system adaptability, which can enhance operational resilience and improve overall worker safety and ergonomics. The validated guidelines offer valuable insights for non-experts in designing collaborative applications focused on human-centered interaction.

Gao et al. (2024) introduced the Inherently Safer and Healthier Design Model for Industrial Workplaces (ISHDM-IW), a mechanistic model aimed at incorporating inherent safety and health principles into industrial workplace design. The ISHDM-IW adapts safety and health risk indicators and uses fuzzy risk representation to evaluate workplace design. A case study demonstrated the model's effectiveness in upgrading workplace safety, reducing the risk level from II to I, and ensuring a safer and healthier work environment. This approach shows the potential for integrating inherent safety and health concepts early in the project planning stage, resulting in better ergonomic outcomes and improved worker well-being in industrial settings.

8. FUTURE DIRECTIONS AND CHALLENGES

Advancements in ergonomic risk assessment are addressing emerging challenges and laying the groundwork for future improvements in occupational safety and health. One critical factor is the influence of individual characteristics, such as obesity, on ergonomic risk. Boocock et al. (2024) conducted a meta-analysis examining the biomechanical and physiological responses of obese individuals during manual handling tasks. Their findings showed that obesity increased horizontal reach distance during lifting and elevated heart rates during repetitive lifting. Increased spinal compression forces and moments were also observed, suggesting that workplace designs and training programs should account for worker body weight to mitigate the risk of musculoskeletal disorders.

The integration of governance and practical application remains a challenge, particularly in settings like clinical trials. Lorch and Vincent (2024) emphasized the importance of aligning regulatory frameworks with real-world practices to enhance safety during early-phase clinical trials. They noted that while governance provides essential guidelines, its practical implementation requires cohesive efforts to ensure safety protocols are effectively applied, ultimately improving participant protection and research outcomes.

User-centered design approaches have proven vital for developing tools that enhance occupational safety. Millet (2024) detailed the creation of the Personal Exposure Reporter system for firefighters within the Sylvester Firefighter Cancer Initiative. Designed to collect data on occupational hazard exposure, the system's development involved 450 firefighters in user-centered research. The positive reception of the system demonstrates the importance of involving end-users in tool design, which can improve usability and acceptance, facilitating better health outcomes.

Real-world implementation of ergonomic assessments presents unique challenges. Simon et al. (2024) conducted a field study using inertial measurement units and in-shoe plantar pressure devices to assess fatigue's impact on ergonomic risk scores among production and office workers. Although significant differences in fatigue were recorded, no major changes were observed in ergonomic risk scores or plantar pressures. This suggests that traditional observational methods may not effectively capture fatigue-related kinematic deviations, and the authors recommend refining these methods for improved sensitivity.

Additionally, Mazaheri et al. (2024) investigated ergonomics assessments in an automotive organization, particularly in the absence of established standards for nutrunners (handheld tightening tools). The study revealed that assessments relied on a combination of objective criteria, such as tool type, and subjective operator feedback. The lack of standardized methods affected the accuracy of musculoskeletal disorder risk estimates. The study highlighted the necessity of developing standardized ergonomic assessment tools to ensure more consistent and accurate evaluations, leading to better health outcomes for workers.

9. CONCLUSION

The landscape of ergonomic risk assessment is undergoing a significant transformation due to the integration of artificial intelligence (AI), wearable technology, and industry-specific approaches. These advancements are reshaping traditional methods, providing more accurate, efficient, and proactive means to identify and mitigate work-related musculoskeletal disorders (WMSDs).

The incorporation of AI has led to the development of sophisticated models capable of analyzing complex data to predict ergonomic risks. Machine learning algorithms and computer vision techniques are now being utilized to assess workers' postures and movements in real-time. This allows for immediate feedback and intervention, enhancing the ability to prevent injuries before they occur. AI-driven tools offer the potential to automate risk assessments, reducing the reliance on manual observations and subjective evaluations.

Wearable technology has emerged as a powerful tool in collecting biomechanical and physiological data directly from workers. Devices such as inertial measurement units, smart sensors, and triaxial load cells provide continuous monitoring of physical strain, posture, and muscle activity. This real-time data collection enables a more precise assessment of ergonomic risks and facilitates personalized interventions tailored to individual workers' needs. Wearable devices also promote worker engagement by providing immediate feedback on their movements and postures.

Industry-specific approaches have further refined ergonomic risk assessments by addressing the unique challenges and requirements of different sectors. For example, in manufacturing, the use of exoskeletons and collaborative robots has been explored to reduce physical strain on workers performing repetitive or heavy tasks. In the healthcare sector, specialized assessment tools have been developed to evaluate the physical load on healthcare professionals during patient handling and movement, aiming to reduce the high incidence of WMSDs in this field.

The adoption of user-centered design principles ensures that the developed technologies are intuitive and meet the actual needs of the workers. By involving end-users in the design process, tools and interventions become more practical and effective, leading to higher acceptance rates and better compliance with ergonomic recommendations.

Despite these advancements, challenges remain in fully realizing the benefits of these technologies. Data privacy concerns, the need for standardization across different tools and methods, and the integration of new technologies into existing workflows are issues that need to be addressed. Additionally, there is a need for ongoing research to validate the effectiveness of these technologies across various industries and to develop guidelines for their optimal use.
In conclusion, the integration of artificial intelligence, wearable technology, and industry-specific approaches marks a significant step forward in ergonomic risk assessment. These advancements offer the promise of safer workplaces, reduced incidence of WMSDs, and improved overall worker well-being. Continued collaboration among researchers, industry professionals, and workers is essential to overcome current challenges and to fully harness the potential of these innovative solutions in promoting occupational health and safety.

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