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Posture in Ergonomics: Review of Muscle Activity, Risk Assessment, and Intervention Effectiveness Across Occupational and Clinical Settings

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ABSTRACT

Posture plays a critical role in ergonomics, influencing muscle activity, risk of musculoskeletal disorders (MSDs), and overall occupational health across clinical and industrial settings. This review synthesizes current literature on muscle activation patterns associated with diverse postures and tasks, risk assessments linking improper postures to MSD prevalence, and various measurement methods including observational tools, biomechanical analysis, wearable sensors, and machine learning techniques. It also examines how task design, work environment, individual factors, and organizational practices affect ergonomic risks. Furthermore, the effectiveness of ergonomic interventions such as exoskeletons, biofeedback, robotic systems, and AI-powered assessment tools is evaluated. Findings reveal that static and dynamic postures differentially impact muscle fatigue and demand, that high-risk postures correlate with increased MSD incidence, and that emerging technologies enhance risk detection and intervention efficacy. Ultimately, integrating personalized ergonomic strategies with innovative technologies and organizational support is essential to promote sustainable workplace health and reduce MSD-related burdens.

Keywords: Posture, Muscle activity, Musculoskeletal disorders, Ergonomic risk assessment, Ergonomic interventions, Wearable sensors, AI-based assessment, Ergonomic design.

1. POSTURE AND MUSCLE ACTIVITY PATTERNS

Variations in muscle activation related to different postures have significant implications for musculoskeletal health across a range of occupational and clinical environments. Electromyography (EMG) has been crucial for objectively quantifying muscle activity and fatigue during both static and dynamic tasks, revealing how specific muscle groups respond to posture demands.

Kappel et al. (2024) compared surgeon muscle activity and posture when using the Versius robotic system versus conventional laparoscopic surgery. Their study employed EMG sensors on 14 muscles and inertial sensors for body motion tracking. Results indicated reduced muscle activity in lower limb muscles (gastrocnemius, vastus lateralis), lumbar erector spinae, and medial trapezius during robotic surgery, contrasting with increased activity in upper limb muscles such as the brachioradialis and triceps. This reflects altered ergonomic demands, where robotic platforms may offload sustained lower limb muscle demands but potentially increase upper limb exertion. Posture analysis showed improved ergonomic suitability in knee flexion-extension and wrist ulnar-radial deviation with robotic assistance, suggesting that posture-induced muscle activation shifts vary by surgical modality.

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In occupational settings involving static tasks, Sanmugum et al. (2024) assessed awkward postures and repetitive motion risks among laboratory workers. Using the Rapid Upper Limb Assessment (RULA) and musculoskeletal discomfort questionnaires, their findings showed high prevalence of neck and shoulder muscle discomfort, indicating elevated muscle strain associated with prolonged static postures and repetitive upper limb activity. Ergonomic risk was notably high (RULA score=7), emphasizing that static postures in laboratory work contribute to elevated muscle activity and fatigue in upper body musculature.

Rony Rinaldho et al. (2022) analyzed military backpack designs affecting soldiers' posture. Here, poor backpack ergonomics can shift muscle demands, affecting postural stability and increasing musculoskeletal strain, particularly on the back and shoulders. Adjusting backpack dimensions to match anthropometric data can reduce muscle overactivation caused by compensatory postural adjustments.

Extending muscle activation analysis to assistive devices, Kuber and Rashedi (2024) evaluated back support exoskeletons during repetitive trunk bending. Using EMG, they found exoskeleton assistance reduced erector spinae muscle activity by up to 1.8% and biceps femoris activity by 10-18%, especially during asymmetrical postures and fatigue. This indicates that posture-supportive technologies can effectively mitigate muscle load and fatigue in trunk extensors and leg muscles during sustained bending activities.

Driving tasks also stress specific muscle groups depending on posture. Li et al. (2024) employed biomechanics modeling to study muscle activation of Chinese drivers under straight-line and steering conditions. Steering notably increased wrist extensor, serratus anterior, deltoid, and triceps brachii activation compared with straight-line driving, highlighting the impact of posture and task type on upper limb muscle demands. Additionally, ergonomic adjustments such as seat back recline influence trunk muscle engagement and spinal load distribution during driving.

Prolonged static postures in the workplace contribute to muscle fatigue and discomfort, as seen in studies of seated workers (Zhang et al., 2025) and operators maintaining constrained postures (Kefala et al., 2023). Muscle groups such as the erector spinae and trapezius are commonly affected owing to sustained activation required to maintain posture.

The variations in muscle activity due to posture are further corroborated by research on occupational tasks involving manual handling, highlighting that heavier weights and increased height lifting elevate muscle stress (Vijaywargiya et al., 2022). Similarly, tasks requiring repetitive fine motor skills, such as surgical procedures, activate specific upper limb muscles linked to particular postures.

2. POSTURAL ERGONOMIC RISK AND MUSCULOSKELETAL DISORDERS

Evidence from a variety of occupational settings illustrates a strong association between poor posture and the prevalence of musculoskeletal disorders (MSDs). Healthcare professionals, industrial workers, drivers, students, and manual laborers consistently exhibit elevated MSD risk linked to high-risk postures, prolonged static positions, and repetitive tasks.

In healthcare settings, multiple studies highlight the high incidence of MSDs attributable to ergonomic challenges. For example, an assessment of laboratory workers showed a significant prevalence of neck (91.8%), shoulder (approximately 86%), and lower back discomfort, with Rapid Upper Limb Assessment (RULA) scores indicating a high exposure to awkward postures (Nata, Hisham, & Mohamad Jamil, 2024). Similarly, in surgical domains, a snapshot study involving general and breast surgeons revealed a median Rapid Entire Body Assessment (REBA) score of 6.17, suggesting medium risk for developing work-related MSDs with operative postures

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implicated prominently (Ho et al., 2025). Ergonomic concerns extend into dental education, where dental students, despite receiving formal instruction, show medium to high risk of musculoskeletal pain, as evidenced by RULA evaluations indicating significant ergonomic strain in neck and limb posture (Sangalli et al., 2023).

Industrial workers represent another group bearing a heavy burden of MSDs related to postural risks. In steel industry workers, muscle pain commonly manifests in the back and knees, with structural equation modeling underscoring the impact of workload, fatigue, and posture on MSDs (Unknown Author, 2023). Similarly, Indian brick molders, predominantly female, face repetitive hand-intensive work combined with poor postures that result in a high prevalence of upper limb musculoskeletal disorders, particularly affecting hands, shoulders, and wrists, validated by RULA analyses showing high-risk upper and lower arm postures (Das, 2022). Cargo handling workers at airports have been found to endure substantial ergonomic risk associated with manual material handling and awkward standing postures, as indicated by Quick Exposure Check (QEC) and Cornell Musculoskeletal Disorder Questionnaire (CMDQ) results showing over 60% prevalence of musculoskeletal symptoms across shoulders, arms, and back (Unknown Author, 2024).

Driving professions are not exempt from postural ergonomic challenges. Tram drivers, confined to prolonged sitting in poorly adaptable cabins, experience moderate to high ergonomic risk as indicated by both RULA and REBA scores of 6, highlighting the biomechanical strain caused by constrained postures (Horina et al., 2025). Professional drivers more broadly are consistently exposed to whole-body vibration, awkward postures, and manual material handling contributing to MSDs, with systematic reviews providing strong evidence for causal associations between these ergonomic hazards and musculoskeletal injury (Joseph et al., 2021). The mismatch between driver anthropometry and seating configuration further exacerbates postural strain and MSD risk (Zhang et al., 2021).

In educational settings, ergonomic mismatches between furniture dimensions and user anthropometrics adversely affect posture and contribute to MSD risks. For instance, primary school children in Nigeria were found to have significant mismatches between their body dimensions and classroom furniture, resulting in deviations from natural sitting angles associated with increased likelihood of back pain and postural abnormalities (Badmos, Alumona, & Adegoke, 2022). Tertiary institution studies similarly report concerning ergonomic inefficiencies, with RULA assessments revealing significant neck and trunk postural deviations among students in seated workstations that could predispose to musculoskeletal discomfort (Venkatason, Achmad, & Sivaguru, 2025).

Manual laborers engaged in physically demanding tasks such as agricultural farming, construction, and tailoring also demonstrate high ergonomic risk. Farming postures involving squatting and stooping contribute to very dangerous REBA scores, with the low back being the most affected body part (Das, 2023). Tailors suffer from low back pain due to prolonged sitting and repetitive work, with systematic literature reviews corroborating the significant impact of poor workstation design and awkward movements on the prevalence of these disorders (Pramesti & Nurcahyo, 2024). Construction workers show high-risk postural scores mainly attributed to repetitive supporting tasks and static loading postures, which are linked with musculoskeletal complaints (Anagha & Xavier, 2023).

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The utilization of observational risk assessment tools such as REBA, RULA, QEC, and CMDQ throughout these studies consistently identifies specific body regions most vulnerable to MSDs, including neck, shoulders, lower back, wrists, and knees. The cumulative evidence strengthens the understanding that ergonomic risk factors such as sustained awkward postures, repetitive motions without breaks, poor workstation design, and misfit between anthropometry and environment markedly increase musculoskeletal discomfort and injury incidence. This consensus is observable across discrete occupational sectors and underscores the imperative for ergonomics-focused interventions and workplace design improvements to mitigate MSD risks.

3. ASSESSMENT METHODS FOR POSTURE AND ERGONOMIC RISK

The evaluation of posture and ergonomic risk has evolved considerably, encompassing a wide array of methodologies across various industries and occupational settings. Observational assessment tools remain foundational in this domain, with instruments such as the Rapid Entire Body Assessment (REBA), Rapid Upper Limb Assessment (RULA), Hierarchical Task Analysis (HTA), and Ovako Working Posture Analysis System (OWAS) frequently adopted due to their practical applicability and ease of use in real-world scenarios. REBA and RULA, for example, have been widely applied to quantify ergonomic risk in tasks ranging from manual handling to surgical procedures and industrial operations (Das, 2022; Putri, 2025; Hazwani Mohd Suadi et al., 2024). HTA provides a structured decomposition of complex tasks into subtasks, facilitating detailed ergonomic risk analysis (Iranian Journal of Ergonomics, 2024), while OWAS offers granular postural classification that aids in prioritizing corrective measures in settings such as construction and assembly line work (Sardinha et al., 2024).

Advancements in biomechanical measurements provide more objective and quantitative insight into postural load and muscle activity. Techniques using motion capture technology, such as those reviewed by Rybnikár et al. (2022), offer high-resolution kinematic data to assess joint angles, joint loading, and movement variability. Although these methods offer superior precision, challenges remain due to their cost, complexity, and the need for specialized expertise. Force platforms and electromyography (EMG) complement these approaches by quantifying muscle activation levels and biomechanical loading during specific tasks, enabling identification of muscle fatigue and strain patterns (Kappel et al., 2024).

Wearable sensors and smart devices have emerged as accessible, real-time posture monitoring solutions. Stefana et al. (2021) systematically reviewed wearable devices designed for ergonomics and found that sensor systems embedded on the body provide a continuous stream of data on posture and movements, which can be leveraged for early detection of harmful postural habits and injury risk. These devices vary from smartwatches to pressure-sensitive insoles and vibrotactile feedback interfaces. Nabilah et al. (2024) demonstrated the utility of surface electromyography (sEMG) sensors in quantifying muscular activity reductions with ergonomic interventions such as custom armrests. Similarly, Maksimović et al. (2022) examined garment-embedded sensors, highlighting their potential to autonomously detect and correct upper body postures, thereby aiding workers in maintaining ergonomically beneficial positions.

The integration of artificial intelligence and machine learning into ergonomic assessments marks a significant step forward. Wang et al. (2021) utilized a binary classification approach along with the Matthews correlation coefficient (MCC) to evaluate the accuracy of machine learning models for predicting hand posture and grip force, illustrating the power of computational models for nuanced ergonomic analysis. Qing et al. (2025) leveraged transfer learning with conditional variational autoencoders (cVAE) to generate diverse ergonomic postures and optimize human-robot collaboration tasks by balancing posture variability with injury risk.

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Moreover, automated posture assessment tools employing computer vision have been piloted with promising results. Kurdi et al. (2025) introduced ErgoGenius, an AI-powered computer vision system that permits continuous ergonomic monitoring without the need for wearable trackers. This tool demonstrated high internal consistency and strong correlation with human assessments, effectively detecting higher risk postures during endoscopic procedures.

Digital human modeling (DHM) and virtual reality (VR) platforms provide immersive environments for ergonomic evaluation and workstation design. Rony Rinaldho et al. (2022) used CATIA software to digitally simulate workstations, facilitating the comparison of ergonomic scores before and after task redesigns. Such simulations allow for rapid prototyping and risk assessments that can inform real-world interventions. Complementing this, Morse et al. (2024) presented ErgoReality, a VR-based ergonomic analysis software encompassing simulation development, data collection, and ergonomic risk analysis. This approach addresses limitations of traditional DHM tools by incorporating motion capture data within a VR context, enabling more realistic and variable human movement assessments.

Additional sensor-based methodologies include video-based 3D human pose estimation frameworks (Paudel et al., 2025) using media-pipe or similar skeletal tracking algorithms, enabling non-intrusive task segmentation and ergonomic risk assessments in real time. Lee et al. (2025) conducted an experimental analysis using electrogoniometers to study the effects of ergonomic chairs on spinal kinematics, demonstrating how biomechanical measurement tools integrate with ergonomic intervention evaluation.

4. EFFECTS OF TASK DESIGN AND WORK ENVIRONMENT ON POSTURE

Workstation configuration and environmental factors critically influence postural health by shaping how individuals assume and maintain body positions during tasks. In office and computer-based environments, studies have shown that seating design and workstation arrangements impact human postural behavior, although the effect of workstation arrangement per se might be subtle compared to chair features. Stone et al. (2022) conducted a factorial design experiment examining different computer workstation setups and chair designs, finding no significant differences in overall postural behavior based on workstation arrangement, while chair features influenced certain posture variables. This reveals that ergonomic chair design is paramount in facilitating healthier postures during computer tasks, potentially more so than mere workspace layout.

Madhav Kuber et al. (2024) studied posture and ergonomics during intubation, demonstrating that the working surface height influences biomechanical forces and operator posture. The study found that adjusting bed height to the level of the xyphoid process, as opposed to the anterior superior iliac spine, reduced laryngoscopy force and improved ergonomic scores. This highlights how simple modifications in task environment dimensions can reduce operator strain and improve posture, which is vital in healthcare settings involving precise manual tasks.

Within industrial and laboratory settings, ambient conditions and task demands also modulate posture and associated ergonomic risks. Lu and Werren (2023) surveyed baggage handlers using a rollertrack conveyor system and found that while handling efficiency improved with the new device, musculoskeletal disorder risk factors such as lifting, pushing, and pulling tasks did not significantly differ in total exposure time. This indicates that task design innovations can enhance productivity but might not always reduce ergonomic risk without specific adaptations addressing posture or load handling.

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In manufacturing and manual labor contexts, task variability and postural demands interact with environmental exposures to influence posture. Anagha and Xavier (2023) used the Rapid Entire Body Assessment (REBA) tool to assess postural risk in construction workers, identifying over-exertion and repetitive motions as main contributors to musculoskeletal strain. Poor workstation design, including suboptimal placement of tools and awkward postures during tasks such as squatting and lifting, was associated with increased risk scores, emphasizing the necessity of ergonomic redesign tailored to task demands.

Sanmugum et al. (2024) evaluated a novel hot-work chair prototype designed to reduce muscle discomfort among workers with prolonged static postures. Their findings indicated a significant reduction in overall muscle discomfort ratings, particularly in areas like the buttocks and lower back, after introducing ergonomically designed seating. This illustrates how seating comfort and support in task environments lessen fatigue and encourage better posture during sustained work. Lighting, thermal conditions, and visual ergonomics further determine posture quality and fatigue. Putri (2025) assessed CCTV operator performance, revealing that poor environmental factors such as inadequate lighting and monitor glare contribute to non-ergonomic postures and visual strain, decreasing operator performance and increasing fatigue risk. Similarly, workstation environmental conditions, including temperature and air velocity, were below comfort standards, exacerbating physical fatigue.

Task-specific physical factors like load magnitude and handling height also shape ergonomic exposures. Vijaywargiya et al. (2022) demonstrated that heavier lifted weights increased biomechanical stress significantly, with loading rates rising linearly beyond waist height. Ergonomics interventions thus need to consider the combination of load and posture to mitigate musculoskeletal stress effectively.

Variations in postural dynamics during sitting or static work also play a role. Zhang et al. (2025) studied leg postural switching motions during sedentary sitting, finding that maintaining one posture progressively increases discomfort and fatigue, whereas periodic posture changes alleviate these symptoms. This suggests that dynamic task design encouraging movement or posture variation can minimize ergonomic risks linked to prolonged static postures.

Ergonomic interventions involving assistive devices and task redesign also show promise in improving posture. For example, Kang and Mirka (2023) demonstrated that wearing a passive back-support exosuit reduced erector spinae muscle activity by 21%, independent of posture asymmetry or mobility restrictions. This indicates that suitable ergonomic assistive technologies can mitigate muscle strain during physically demanding postures.

5. ERGONOMIC INTERVENTIONS AND ASSISTIVE TECHNOLOGIES

Ergonomic interventions and assistive technologies have demonstrated significant potential in reducing muscle strain, the risk of musculoskeletal disorders (MSDs), and enhancing posture outcomes across a variety of occupational and clinical settings. One of the prominent advancements in this field is the use of passive back-support exosuits. Kang and Mirka (2023) investigated the effects of a passive back-support exosuit on muscle activity during trunk posture maintenance tasks and found a substantial reduction of 21% in erector spinae muscle activity regardless of posture asymmetry or lower extremity restrictions. This supports the use of exosuits as effective aids in mitigating muscle fatigue and discomfort in physically demanding dynamic or static trunk postures.

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Robotic systems have also emerged as crucial ergonomic support tools. For example, Navas-Reascos et al. (2022) provided empirical evidence demonstrating that integrating a collaborative robot (cobot) into wire harness assembly processes significantly reduced non-ergonomic postures among workers, as measured by Rapid Upper Limb Assessment (RULA) and Job Strain Index (JSI). This robotic assistance diminished ergonomic risk scores from urgent-risk levels to acceptable values, strengthening the case for cobots in labor-intensive manufacturing to enhance worker safety and productivity.

In surgical environments, technology aiming to improve ergonomics is evolving rapidly. Kappel et al. (2024) found that robotic surgery platforms reduce muscle activity in key postural muscles and improve certain ergonomic postures compared to conventional laparoscopic surgery, with lower muscle loads in the gastrocnemius and erector spinae. Similarly, Ajmera et al. (2025) compared the ergonomic risk of 3D-exoscopes versus traditional operating microscopes in otologic surgery, reporting significantly lower ergonomic risk scores and reduced physical strain when using 3D-exoscopes. These findings indicate that integrating advanced visualization and robotic tools in surgery can alleviate the physical demands related to prolonged static and awkward postures.

Beyond mechanized supports, biofeedback devices have shown promise in aiding posture correction. Leung et al. (2022) assessed the impact of a commercially available posture-training device during otolaryngology procedures and discovered a modest yet meaningful 5% average improvement in upright operating posture time after biofeedback intervention, especially noted in certain procedure subtypes. While the intervention's efficacy varied among individuals, it highlights the potential of wearable feedback technology in reinforcing ergonomic postures, although it may require complementary training programs for maximum effect.

Posture training programs utilizing photographic evaluation have gained traction in educational settings as well. Esnault et al. (2025) demonstrated significant improvements among pediatric dentistry students using a protocol involving ergonomic self-assessment with photographic feedback. This method led to notable reductions in ergonomic risk scores, underscoring the benefits of visual and self-assessment tools in fostering awareness and encouraging postural improvements. Additionally, Stefana et al. (2021) reviewed various wearable devices and highlighted their utility in continuous posture monitoring and risk reduction through real-time feedback and alerts.

In industrial and manual work environments, ergonomic equipment modifications are key to reducing physical strain. Varghese et al. (2024) reported that Ayurvedic therapists exhibited a high prevalence of MSDs attributed to improper posture during different procedures, emphasizing that proper adherence to ergonomics principles and equipment redesigns could substantially reduce such risks. Furthermore, Kang and Mirka (2023) demonstrated that passive support through exosuits reduces muscle demands during sustained postures, suggesting practical applications for various labor-intensive tasks.

Recent advances in artificial intelligence (AI) have also contributed significantly to ergonomic assessments and interventions. El Kurdi et al. (2025) piloted ErgoGenius, an AI-powered computer vision tool for continuous posture assessment without wearable sensors, showing high accuracy and strong correlation with human appraiser scores in detecting elevated ergonomic risks. Qing et al. (2025) further leveraged transfer learning techniques to enhance generative models in posture prediction, improving variability and accuracy, which underpins more adaptable ergonomics simulations and assessments.

Complementing AI, virtual reality (VR) technologies have become useful platforms for ergonomic analysis and workstation design. Morse et al. (2024) introduced ErgoReality, a VR simulation software that captures real-time worker movements for ergonomic analysis, overcoming

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limitations of traditional digital human modeling and enabling cost-effective and efficient workstation design testing. VR environments allow iterative ergonomic assessments before physical implementation, promoting better workplace layout and posture optimization.

Additional interventions, including ergonomic chair design, have demonstrated measurable improvements in posture and discomfort relief. Sanmugum et al. (2024) developed a hot-work chair prototype reducing muscle discomfort in buttocks and lower back significantly compared to existing inadequate seating options, highlighting the importance of seating ergonomics.

6. INDIVIDUAL AND ORGANIZATIONAL FACTORS INFLUENCING POSTURE

Individual anthropometric differences play a critical role in influencing posture and ergonomic risk across various occupational settings. For instance, Abushgair et al. (2025) highlight how mismatches between workstation dimensions and individual body sizes directly affect ergonomic risk levels. Their study underscored the significance of accounting for anthropometric variability in designing workstations, particularly when using digital human modeling and posture assessment tools. Such variability can produce discrepancies in posture comfort and musculoskeletal loading, emphasizing the necessity for adaptive or customizable ergonomic solutions.

Gender differences also influence posture and musculoskeletal disease risk. Mohd Suadi et al. (2024) found that female workers experienced higher prevalence rates of musculoskeletal disorders (MSDs) associated with awkward postures and repetitive motions, which were further affected by factors such as age and shift work status. Similarly, Das (2022) identified that women brick molders faced elevated upper limb musculoskeletal risks compared to controls, attributed not only to repetitive task demands but also physiological differences like muscle strength and cardiovascular responses. These findings suggest that gender-specific ergonomic interventions may be warranted to address unique biomechanical and physiological susceptibilities.

Experience and work tenure also modulate ergonomic risk and posture quality. Vijaywargiya et al. (2022) noted that experienced thoracic surgeons demonstrated better ergonomic scores and faster instrument manipulation, indicating that skill development and experience can lead to improved postural strategies and reduced musculoskeletal strain. Conversely, Jung et al. (2025) found that personal routines heavily influence posture choices, implying that even experienced workers may develop suboptimal habits over time without adequate ergonomic education or intervention.

Workload, fatigue, and psychosocial factors further contribute to posture quality and MSD risk. The work of Mohd Suadi et al. (2024) showed a significant correlation between high workload, increased fatigue levels, and elevated ergonomic risk scores in laboratory workers. Similarly, Majumder et al. (2024) emphasize that night shift work disrupts circadian rhythms, inducing fatigue and sleep disturbances, which negatively impact posture and increase injury risk. Psychosocial stressors such as job demand and monotony have been recognized as contributors to musculoskeletal complaints among agricultural workers (Das, 2023) and drivers (Leder Horina et al., 2025), highlighting the multifactorial nature of ergonomic risk beyond physical postures.

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Organizational practices and workplace policies significantly influence posture maintenance and ergonomic risk reduction. Majumder et al. (2024) advocate for ergonomic interventions that include rotational shift work and dynamic postural changes to mitigate health risks associated with fatigue and static postures. Training programs with real-time feedback and self-assessment tools have demonstrated efficacy in improving workers' ergonomic behaviors. For example, Esnault et al. (2025) showed that photography-based ergonomic self-assessment protocols led to statistically significant improvements in dental students' working postures. Similarly, Leung et al. (2022) demonstrated that posture-training devices providing biofeedback could increase upright posture time in otolaryngology surgeons, though effectiveness varied among individuals, suggesting a need for diverse intervention approaches.

Moreover, organizational support in terms of ergonomic education, provision of adjustable equipment, and ergonomic culture promotes sustained posture improvements. Garcia et al. (2025) discuss the barriers faced by cleft care surgeons, including lack of ergonomic training and limited access to ergonomic devices, which exacerbate musculoskeletal issues. Addressing such barriers through organizational commitment to ergonomic initiatives can substantially reduce MSD prevalence and improve worker well-being.

Ergonomic risk is also modulated by individual physical capacity and health status. Vijaywargiya et al. (2022) found that pre-existing musculoskeletal conditions did not significantly affect surgeon posture risk but highlighted the importance of ongoing intervention. Additionally, Adequate anthropometric matching as discussed by Qing et al. (2025) in human-robot collaboration tasks reduces awkward postures by optimizing operation points, demonstrating that integrating individual characteristics into task design mitigates ergonomic risks.

7. IMPLICATIONS FOR ERGONOMIC DESIGN, TRAINING, AND SUSTAINABILITY

Current evidence highlights the necessity of integrating ergonomic design, continuous training, and adaptive systems to foster sustainable health outcomes and enhance productivity across diverse occupational and clinical environments. Ergonomic designs must be tailored to accommodate worker anthropometry, task demands, and environment-specific considerations to mitigate risks associated with prolonged static postures, repetitive motions, and awkward positioning.

In clinical settings, such as surgical subspecialties, ergonomic interventions have proven critical. Garcia et al. (2025) emphasize the integration of ergonomic principles to improve surgeons' musculoskeletal health and career longevity, advocating for the incorporation of tailored ergonomic equipment, visualization aids, and comprehensive ergonomic curricula. Their systematic review suggests that combining ergonomic tool designs with regular training fosters both operator comfort and performance improvements, which is instrumental for the demanding, prolonged procedures typical in cleft care and other microsurgeries.

Deployment of wearable sensor technologies and automated ergonomic assessment tools represents a frontier in sustaining proper posture during work. El Kurdi et al. (2025) evaluated the ErgoGenius system—a computer vision-based tool providing continuous posture assessment and feedback without intrusive wearables—demonstrating its high correlation with human raters and its utility in real-time ergonomic risk detection. Such technology enables timely intervention to correct postural deviations before musculoskeletal disorders develop, promoting sustainability in ergonomics through proactive risk management.

Similarly, digital human modeling and virtual reality (VR) applications facilitate ergonomic design and training within virtual simulations. Morse et al. (2024) introduced ErgoReality, a VR-based platform that enables workers to engage in simulated workstations, capturing full-body kinematics for ergonomic analysis. The technology enhances ergonomic evaluation accuracy and

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expedites workstation design iterations, reducing physical prototype costs and accelerating implementation of improved workstation configurations. This approach aligns well with the needs of industries requiring rapid customization for worker safety and performance.

Training programs focused on posture education and behavioral modification have shown promise in diverse settings. Esnault et al. (2025) demonstrated that pediatric dentistry students who engaged in photographic self-assessment protocols significantly improved their working posture, reinforcing the importance of visual feedback and ergonomic awareness in education. Equally, Leung et al. (2022) documented that biofeedback devices can enhance surgeon posture ergonomics during otolaryngologic procedures, although variability among users points to a requirement for personalized or alternative teaching methodologies.

Ergonomic equipment redesigns, informed by anthropometric data and task analysis, are essential components for sustainable ergonomic solutions. In heavy manual labor and industrial assembly, workstation redesign incorporating ergonomic principles reduces physical strain; for example, evaluations of welding workstations and cargo handling environments emphasize lowering physical workload through adjustable furniture and optimized task layouts (Sanmugum et al., 2024). The role of exoskeletons and exosuits also emerges as an effective biomechanical intervention to decrease muscle activity and fatigue during demanding postures or repetitive trunk bending (Kang & Mirka, 2023; Kuber & Rashedi, 2024), representing assistive technology avenues to extend workers' endurance and prevent injury.

Anthropometric variability necessitates individualized consideration in ergonomic design. Abushgair et al. (2025) underline that postural solutions must account for diverse body types to optimize comfort and reduce musculoskeletal risks, while accounting for gender, experience, and workload differences helps tailor interventions appropriately (Mohd Suadi et al., 2024). Organizations that foster ergonomic safety cultures by incorporating training, ergonomic evaluations, and adaptable workstation policies are better positioned to sustain worker health and maximize productivity, as highlighted in hospital-based ergonomics implementation studies (Rusli & Santoso, 2025).

8. CONCLUSION

This comprehensive review highlights the pivotal role of posture in determining muscle activity patterns, the prevalence of musculoskeletal disorders, and overall ergonomic risk in diverse occupational and clinical settings. Evidence consistently shows that both static and dynamic postures alter muscle demand and fatigue, influencing the onset of MSDs, especially in high-risk environments characterized by repetitive or prolonged postures. Advancements in assessment techniques—from traditional observational tools to modern AI-based systems and wearable sensors—have enhanced the precision and efficiency of ergonomic evaluations. The review also underscores the critical influence of task design, work environment, and individual and organizational factors on posture quality and ergonomic risk. Various ergonomic interventions, including exoskeletons, biofeedback devices, and robotic assistance, have demonstrated effectiveness in reducing muscle strain and improving posture. However, the variability in individual anthropometric and psychosocial factors necessitates personalized approaches, supported by organizational policies and continuous training. Future research should focus on integrating advanced technologies with sustainable ergonomic practices and evaluating long-term outcomes of assistive interventions. Overall, adopting proactive, multi-faceted ergonomic strategies is essential to promoting workplace health, reducing MSD burden, and enhancing productivity across occupational contexts.

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