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Human-Centered Safety and Ergonomic Design for Women in High-Risk Industrial Occupations: A Systematic Review Within Intelligent Systems Context

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ABSTRACT

Women's participation in high-risk sectors such as mining, construction, transportation, and healthcare continues to increase, yet industrial safety and ergonomics remain dominated by gender-neutral design assumptions. This systematic review synthesizes evidence on physical, psychosocial, and organizational challenges faced by women in hazardous environments through a human-cantered systems lens. Following PRISMA 2020 guidelines, 24 peer-reviewed studies (2010–2025) from Scopus, Web of Science, and PubMed were analyzed. The literature highlights exposure to musculoskeletal disorders (MSDs), PPE mismatch, postural load, and inequitable access to safety resources. Thematic analysis reveals that ergonomic inequalities intersect with exclusion from safety training and organizational barriers in risk management. Findings underscore the need for interdisciplinary approaches integrating ergonomics, intelligent systems, and gender studies to enable safer and more inclusive workplaces for women in high-risk occupations.

Keywords: Occupational health and safety, Ergonomic design, Women workers, High-risk occupations, Industrial sectors, Smart systems, Psychosocial hazards

INTRODUCTION

Women's increasing participation in high-risk industrial occupations represents a major workforce shift. Although sectors such as mining, construction, transportation, and industrial manufacturing have begun incorporating women due to labor demands and equality policies, tools, workstations, and smart safety systems remain aligned with male anthropometry (Read et al., 2022). Gender-neutral OHS frameworks overlook disparities in risk exposure, musculoskeletal strain, and PPE compatibility (Laberge et al., 2020).

Women frequently perform repetitive and cognitively low-control tasks that increase ergonomic load, and encounter equipment incompatible with their physical capacities. These mismatches elevate MSD risk and fatigue, while psychosocial conditions—exclusion from safety communication, limited decision-making, stigmatization—further increase vulnerability

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(Kallur et al., 2021). Social pressures to conceal discomfort disrupt hazard reporting and delay corrective action.

Intelligent systems such as wearable sensors, cyber-physical monitoring, computer-vision posture analysis, adaptive PPE, and AI-based workload estimation have the potential to improve ergonomics. However, male-centered datasets risk reproducing gender biases. Within the Human–System Integration domain, understanding how gender influences worker–technology–organization interactions is essential. This study systematically reviews women-specific ergonomic and safety risks in high-risk occupations and discusses how human-centered smart systems can support inclusive design.

GENDER, ERGONOMICS, AND HUMAN–MACHINE SYSTEM INTERACTION IN HIGH-RISK INDUSTRIAL OCCUPATIONS

Although women's employment in hazardous sectors has increased, industrial systems still reflect male physiological norms (Laberge et al., 2020). Tools, machines, workstations, and PPE often fail to match women's anthropometric profiles, contributing to postural deviation, MSDs, and reduced performance (Ishwarya et al., 2021). Poor PPE fit—oversized gloves, loose harnesses, improperly sealed respirators—impairs both safety and task performance (Read et al., 2022; Kallur et al., 2021). Women construction workers report dissatisfaction with PPE and mobility constraints, leading to increased tripping and falls (Onyebeke et al., 2016). In mining, inadequate respirator fit heightens exposure to dust and gases (Hall et al., 2024).

Psychosocial and organizational conditions compound these risks. Women often face job insecurity, exclusion from informal communication, and limited participation in safety decision-making (Laberge et al., 2020). Masculinity norms such as endurance discourage reporting of ergonomic discomfort (Read et al., 2022). Consequently, vulnerabilities remain invisible and safety systems lose adaptive capacity.

Despite being assigned "lighter" tasks, women experience equal or higher MSD risk due to repetitive motions, fine motor workloads, and monotony. Gendered exposure patterns persist: women face repetitive tasks, psychosocial pressure, and certain chemical exposures, while men encounter heavier loads and acute hazards (Biswas et al., 2021). Thus, gender cannot be treated as a demographic variable but as a driver of risk structure. Laberge et al. (2020) advocate integrating biological and social determinants, while Read et al. (2022) call for revising ergonomics methodologies to generate equitable outcomes. Underrepresentation of women in OSH research and lack of gender-disaggregated data limit evidence-based solutions.

Smart safety technologies—real-time posture monitoring, sensor-integrated PPE, digital twins, AI-based ergonomic assessment—offer potential but reproduce inequities when built on nonrepresentative datasets. Genuine human-centered integration requires gender-sensitive design principles across all stages of development and implementation.

METHOD

This study conducts a systematic review and qualitative synthesis of ergonomic and safety issues experienced by women in high-risk industrial

settings. Following PRISMA 2020 guidelines, peer-reviewed studies from Scopus, Web of Science, and PubMed (2010–2025) were retrieved using keywords related to women workers, high-risk sectors, occupational safety, MSDs, PPE, and risk perception. Of 286 records, studies lacking ergonomic or safety outcomes, empirical evidence, or women-specific data were excluded, resulting in 24 eligible publications. The process is summarized in Figure 1.

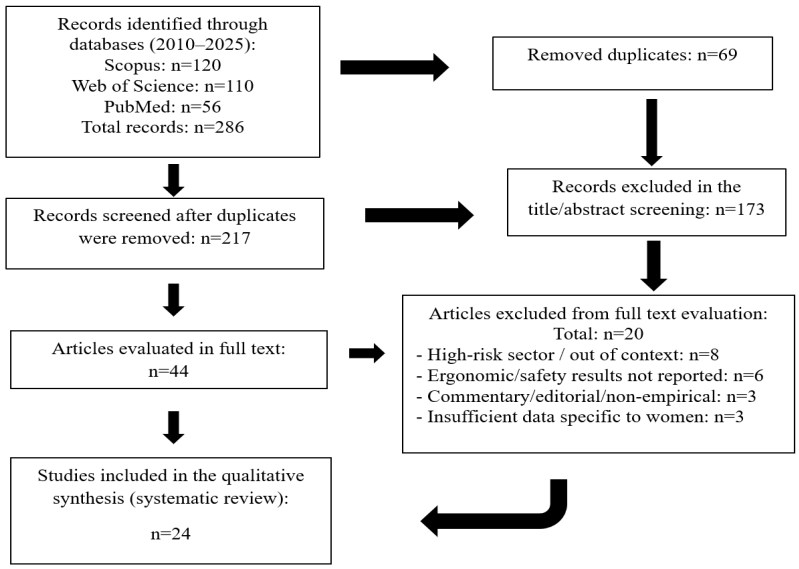

Figure 1: Flow chart of the study selection.

Thematic content analysis was applied to identify recurrent patterns. Three major themes emerged: (1) biomechanical and anthropometric mismatches, (2) psychosocial and organizational stressors, and (3) systemic inequities in safety management. These themes were interpreted through a human-centered systems framework emphasizing gender-sensitive ergonomic integration in OSH practices.

RESULTS

A total of 24 studies were included in this systematic review. These encompass primary empirical research on ergonomic and safety experiences of women in high-risk sectors, as well as systematic/narrative reviews, meta-analyses, and theoretical frameworks addressing gender and occupational health/safety (OHS).

Sectors and contexts: Construction emerges as a key field due to PPE fit and musculoskeletal disorders. Onyebeke et al. (2016) and Oo and Lim (2023) examined PPE access and satisfaction among women construction workers, while Paramasivam et al. (2024), Reddy et al. (2016), and Ishwarya et al. (2021) reported high MSD prevalence and postural risks. In mining, studies by Eiter et al. (2023), Arthur and Busia (2022), Hall et al. (2024), Heimann et al. (2023), and Shaikh et al. (2022) describe respiratory hazards,

PPE shortages, and gendered job divisions. Agricultural settings show repetitive and physically demanding tasks, anthropometric mismatches, and limited rest periods (Mishra et al., 2024). In garment manufacturing, static postures and repetitive upper limb movements increase MSD symptoms among sewing machine operators (Öztürk & Esin, 2011). Healthcare and laboratory environments similarly exhibit risks related to prolonged standing and unsuitable workstation design (Fikre et al., 2024).

Cross-sectoral evidence: Broader analyses connect sector-specific findings to general gendered risk structures. Studies such as Matuszewska (2025), Unverzagt et al. (2024), Biswas et al. (2021, 2022), Lee (2025), Santoro (2022), Bolghanabadi et al. (2024), and Cattani and Rizza (2024) examine MSD, psychosocial stress, accident risk, and mental health across multiple sectors, offering both contextual depth and comparative insight.

Research designs: Methodological heterogeneity is notable. Field-based studies provide detailed indicators of day-to-day exposure through focus groups, surveys, ergonomic observational tools (REBA, RULA), medical assessments, or official datasets (Onyebeke et al., 2016; Oo & Lim, 2023; Paramasivam et al., 2024; Reddy et al., 2016; Ishwarya et al., 2021; Öztürk & Esin, 2011; Hall et al., 2024; Arthur & Busia, 2022; Cattani & Rizza, 2024; Migliore et al., 2021). Systematic and narrative reviews, including those by Eiter et al. (2023), Mishra et al. (2024), Unverzagt et al. (2024), Biswas et al. (2021, 2022), Shaikh et al. (2022), and Bolghanabadi et al. (2024), identify recurrent risk patterns, gaps, and methodological limitations.

Theoretical and methodological contributions: Theoretical works clarify how gender can be systematically integrated into ergonomics and OHS. Conti (2023) and Forssberg et al. (2022) develop gender-sensitive OHS approaches, while Santoro (2022) provides an intersectional view of physical, biological, ergonomic, and psychosocial risks. These studies inform concepts such as gender-responsive risk assessment, gender mainstreaming, and systemic vision, linking micro-level field findings with broader framework.

Geographical distribution and sample characteristics: Country context shapes women's exposure in high-risk occupations. In high-income settings, women experience persistent PPE mismatch, MSD, and psychosocial stress despite advanced OHS systems (Onyebeke et al., 2016; Oo & Lim, 2023; Hall et al., 2024; Cattani & Rizza, 2024; Matuszewska, 2025; Unverzagt et al., 2024). Studies from middle- and low-income contexts show intensified risks from limited resources, weak ergonomics regulation, and precarious work (Paramasivam et al., 2024; Reddy et al., 2016; Ishwarya et al., 2021; Öztürk & Esin, 2011; Fikre et al., 2024; Arthur-Holmes & Busia, 2022). Sample sizes range from small qualitative groups (Onyebeke et al.) to large datasets (Cattani & Rizza), providing both depth and generalizability.

Time span and thematic focus: Studies span 2011–2025, with growth after 2020, and cluster around five domains: MSD and physical workload; PPE and anthropometric inequality; psychosocial stress and work–family conflict; gendered task allocation and organizational exclusion; and gender-blind OHS policies. These align with the review's core themes of biomechanical/anthropometric mismatch, psychosocial-organizational stressors, and systemic design inequities.

Table 1: Summary of included studies.

No	Author(s- – Year	Country Context	Sectors	Research Design	Sample / Data Source	Main Ergonomic / OHS Outputs	Gender Dimension / Notes
1	Onyebeke et al., 2016	USA	construction	Qualitative study (focus group interviews)	23 female construction workers	PPE/PPE incompatibility; oversize and inappropriate design of gloves, harnesses, boots and outerwear; perception of safety culture	PPE is designed according to male anthropometry; women's views are not taken into account, resulting in feelings of exclusion and avoidance of PPE use
2	Eiter et al., 2023	Various countries / literature	Mining (general)	Narrative compilation	Secondary analysis of studies on women miners	Women's ergonomic, physical and social risk exposure in mining; gaps in OSH practices	Women are a minority in a male-dominated work environment; women-specific OSH research and data collection are inadequate.
3	Oo & Lim, 2023	Australia	Construction	Quantitative survey study	Women workers in the Australian construction industry	PPE satisfaction (low satisfaction in functional, aesthetic, ergonomic dimensions)	"Unisex" PPE is actually made to measure for men; women's needs are not adequately reflected in the design and supply processes.
4	Paramasivam et al., 2024	India	Construction (rebar workers)	Quantitative comparative study	250 female + 250 male rebar workers	MSD prevalence (60% in women); increased risk with shoulder and back pain, improper posture and long working hours	Gender-specific machine learning framework (GS-ML-MSD2F) is recommended; women have a significantly higher risk of MSDs
5	Santoro et al., 2022	Mainly Italy / Europe	Multiple sectors (overall employment)	Narrative compilation	Literature on female and male employees	Differences in physical, biological, ergonomic and psychosocial risks; higher MSD and psychosocial risks in women	Work-family conflict, mobbing, and emotional burden are emphasized among women; the need for gender-sensitive OHS is highlighted.
6	Biswas et al., 2021	Various countries	Multiple sectors	Scoping review / systematic screening	Occupational exposure studies for the period 2009–2019	Differential exposure patterns to chemical, ergonomic, and psychosocial hazards by gender	Many studies underreport gender disparities; gender-blind approach in OSH research is being criticized
7	Reddy et al., 2016	India	construction	Cross-sectional quantitative study	Construction workers (men and women)	Prevalence of musculoskeletal health problems; MSD associated with heavy physical work and improper ergonomics	The physical workload and ergonomic challenges of women workers are emphasized; although gender differences are not fully analysed, women are considered a vulnerable group.

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Table 1: Continued.

No	Author(s- – Year	Country Context	Sectors	Research Design	Sample / Data Source	Main Ergonomic / OHS Outputs	Gender Dimension / Notes
8	Fikre et al., 2024	Ethiopia (eastern region)	Health laboratories	Cross-sectional survey + ergonomic assessment	Health laboratory professionals (mostly women)	Prevalence of MSD; inappropriate work surfaces, repetitive pipetting, prolonged standing	A female-dominated profession; poor ergonomic practices create high risks for female employees
9	Matuszewska et al., 2025	Various countries	Multiple sectors	Meta-analysis	Secondary analysis of MSD studies in different industries	The relationship between MSD and work factors; work-related dimensions of musculoskeletal disorders in different sectors	Women's exposure patterns in high-risk positions are more complex; gender-based analyses need to be strengthened
10	Mishra et al., 2024	Various (agricultural contexts)	Agricultural industries	Systematic review	Studies on female agricultural workers between 2010 and 2023	High physical workload (manual handling, bending, repetitive movements) and increased MSD in the waist, shoulder, and wrist	The tools used by female agricultural workers are based on male anthropometry; gender-sensitive ergonomic design and rest arrangements are recommended.
11	Lee, 2025	Various countries (especially Europe/N. America)	Multiple sectors	Systematic review	82 studies comparing male-female exposure differences	Repetitive motion, static posture, and fine motor work exposure in women; heavy lifting, noise, and chemical exposure in men	Gender-neutral discourse in OSH research criticized; gender blindness and need for policy awareness highlighted
12	Bolghanabadi et al., 2024	Various countries	Multiple sectors	Compilation (based on primary data studies)	OSH research on women employees in the last decade	Ergonomics, stress, back/shoulder pain, sleep problems, burnout	The intersection of ergonomic and psychosocial burden in women's occupational health experiences is discussed; the need for gender-sensitive policy
13	Conti, 2023	Italy / Europe	General (theoretical OSH framework)	Theoretical article	Social sciences and OSH literature	Systemic vision of gender in OSH; ergonomics and risk policies based on male norms	A framework aligned with feminist ergonomics, gender-responsive risk assessment and EU/ILO 'gender mainstreaming' objectives is proposed.

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Table 1: Continued.

No	Author(s- – Year	Country Context	Sectors	Research Design	Sample / Data Source	Main Ergonomic / OHS Outputs	Gender Dimension / Notes
14	Cattani &Rizza 2024	EU countries	General employment (high-risk and labor-intensive jobs subgroup)	Quantitative study (EU-LFS data analysis)	38,066 working women	The relationship between occupational gender segregation and depression, burnout, and mental health indicators	Mental health problems are higher among women working in high-risk/physically labour-intensive sectors; psychosocial stress mediation is emphasized
15	Unverzagt et al., 2024	Various countries	Physically demanding jobs (multiple sectors)	Systematic review + meta-analysis	24 studies (≈32,000 women)	Repetitive heavy lifting and prolonged standing increases the risk of hip osteoarthritis (OA) by 1.6–2.3 times.	Biomechanical load and hormonal factors are evaluated together in women; ergonomic job design and job rotation are critical
16	Arthur-Holmes,&Busia 2022	Ghana	Small-scale gold mining	Empirical study (mixed/ qualitative based)	Women + virtual miners	Chemical exposure (mercury), respiratory problems, musculoskeletal strains; lack of PPE	Exclusion from safety training, limited access to PPE and gendered division of labour; health inequalities
17	Hall et al., 2024	USA	Coal mining	Observational/ clinical screening	1,850 female miners	Radiographic respiratory findings (pneumoconiosis, etc.); fatigue due to long shifts	Biological differences and PPE mismatch in women may increase risks; psychosocial isolation and stress are reported
18	Heimann ve ark., 2023	Various countries	Industrial mining	Narrative compilation	Literature on women miners and mining organizations	The relationship between organizational structure, safety culture and gender roles	Women are squeezed into support roles and excluded from leadership and technical positions, which impacts safety behaviors and risk communication
19	Ishwarya et al., 2021	India	construction	Ergonomic observation (REBA, RULA)	120 construction workers	72% of workers are in the high postural risk group; serious musculoskeletal problems in the waist and shoulder area	Repetitive bending/leaning movements are more pronounced in female workers; job-task redesign and equipment adaptation are recommended

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Table 1: Continued.

No	Author(s- – Year	Country Context	Sectors	Research Design	Sample / Data Source	Main Ergonomic / OHS Outputs	Gender Dimension / Notes
20	Shaikh et al., 2022	Various countries	Mining	Compilation	Studies on MSD risk factors in mining	Repetitive motion, heavy lifting, vibration, long shifts are key factors in the development of MSD.	Differences in physical capacity, anthropometric discrepancy, and psychosocial stress combine to create higher risk in female miners.
21	Migliore et al. 2021	Various countries / Europe in particular	Various business organizations	Quantitative study	9,749 women and 10,374 men working in different work organization models	Gender differences in exposure to psychosocial and ergonomic factors and work-related health issues in the workplace	Shift workload, work intensity and task rotation often lead to women working in repetitive and low-control jobs, increasing their risk of neck, shoulder and back pain.
22	Biswas, at al. 2022	Various countries	Multiple sectors	Systematic review	Secondary analysis of work accident and occupational injury studies	Women experience more psychosocial stress and MSD; men experience more physical trauma	Inappropriate use of equipment and protective clothing increases risk of injury in women; gender differences highlighted
23	Forssberg at al. 2022	Various countries	General OHS research	Conceptual/ methodological article	OSH literature and research practices	Integrating gender into systematic OSH research (why and how)	Call for gender mainstreaming and gender-responsive risk assessment; emphasis is placed on the need to consider gender as a structural category
24	Öztürk & Esin, 2011	Türkiye	Garment/ sewing machine operators	Cross-sectional survey + observational ergonomic analysis	Female sewing machine operators	Widespread pain in the neck, shoulder, back, and waist regions; static sitting, repetitive upper extremity movements, continuous pedal use	Workstations are not suitable for women's anthropometry; lack of ergonomic arrangement increases biomechanical loading in women

Theme 1: Biomechanical and Anthropometric Mismatches

Work systems designed around male bodies create ergonomic disadvantage for women. PPE fit is the clearest case: women face oversized gloves, boots, and harnesses that impair mobility and increase risk (Onyebeke et al., 2016; Oo & Lim, 2023). In mining, limited PPE access and inappropriate sizing drive fatigue and non-use (Arthur & Busia, 2022; Hall et al., 2024). Agriculture and garment production show similar effects through tool and workstation mismatch (Mishra et al., 2024; Öztürk & Esin, 2011).

MSD prevalence is strongly linked to postural strain and repetitive tasks. High-risk groups are reported in construction, rebar work, laboratories, and manufacturing (Paramasivam et al., 2024; Reddy et al., 2016; Ishwarya et al., 2021; Fikre et al., 2024; Öztürk & Esin, 2011). Long-term data show elevated rates of chronic conditions such as hip osteoarthritis (Unverzagt et al., 2024) and dual exposure profiles (Matuszewska, 2025). Organizational factors—shift burden, task rotation, and gender bias—amplify biomechanical risk (Shaikh et al., 2022; Migliore et al., 2021).

Theme 2: Psychosocial and Organizational Stressors

Ergonomic inequalities are reinforced by work organization and culture. Women are concentrated in low-status or supportive roles, excluded from technical positions and safety decision-making (Eiter et al., 2023; Heimann et al., 2023; Arthur-Holmes & Busia, 2022). This translates into unequal access to safety information, PPE, and training.

Psychosocial burdens—role conflict, burnout, emotional stress—are consistently higher among women (Cattani & Rizza, 2024; Santoro, 2022). Low control, repetitive tasks, and poor social support correlate with pain, fatigue, sleep problems, and turnover intentions (Bolghanabadi et al., 2024; Hall et al., 2024). The "double burden" of paid and domestic work intensifies risks in labor-intensive roles (Migliore et al., 2021; Santoro, 2022; Biswas et al., 2022; Shaikh et al., 2022).

Theme 3: Systemic Design Inequalities and Risk Governance

Women's ergonomic and safety challenges in high-risk occupations are shaped not only by equipment and workstation design, but by systemic risk governance that reproduces male norms; "gender-neutral" OHS practices obscure women's exposures, as shown by Biswas et al. (2021), who identify significant gender differences in chemical, ergonomic, and psychosocial risks that are often unreported, and by Lee (2025), who notes that women are concentrated in repetitive and static tasks while men are assigned heavy or chemical-intensive roles, yet design standards are derived from male samples; psychosocial burdens such as work–family conflict and chronic stress identified by Santoro (2022) and Bolghanabadi et al. (2024) remain largely absent from institutional risk assessments; recent frameworks call for structural integration of gender, with Forssberg et al. (2022) advocating gender mainstreaming and gender-responsive risk assessment and Conti (2023) showing how OHS historically assumes the male worker as "default,"

framing women's ergonomic problems as deviations; systemic exclusion reinforces risks, as women are marginalized from technical roles and decision-making in mining (Eiter et al., 2023; Heimann et al., 2023) and face limited PPE access and training (Arthur-Holmes & Busia, 2022), while gender-biased safety cultures and work–life imbalance increase MSD prevalence (Shaikh et al., 2022); although human-centered smart systems such as wearable sensors and AI-supported ergonomics could make women's workload profiles visible, the absence of gender-disaggregated data risks reproducing gender-blind patterns (Biswas et al., 2021; Lee, 2025; Forssberg et al., 2022; Conti, 2023), and the prominence of concepts like "woman, worker, risk, musculoskeletal, ergonomic" in Figure 2 confirms that inequalities in women's workplace safety and ergonomics constitute a recurrent and central theme in the literature.

Figure 2: Word cloud representing the most used words.

CONCLUSION

Women's ergonomic and safety disadvantages in high-risk occupations arise from systemic design and gender-blind work organization rather than individual deficits, as repetitive motion, static posture, and PPE mismatch intersect with psychosocial exclusion and labor segmentation (Biswas et al., 2021; Santoro, 2022; Bolghanabadi et al., 2024). The historical reliance on the "male norm" in OHS standards constrains evidence production and policy development, underscoring the need for gender-sensitive risk assessment as a core design principle rather than an ethical add-on (Forssberg et al., 2022; Russo et al., 2025). Although smart systems, wearable sensors, and adaptive PPE can reveal gendered exposure profiles, technologies built on gender-blind datasets risk reproducing existing inequalities (Biswas et al., 2021). Sustainable safety performance therefore requires structural reforms that institutionalize gender-sensitive data practices, ergonomic design, and inclusive governance mechanisms.

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