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Workplace health promotion among industrial workers:

Beyond the machine through flexibility, compensation, and adaptation

Sasha Javanmardi

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Examination board

Chair:

PD Dr. Udo Wehmeier

Reviewer:

Prof. Dr. Jürgen Freiwald M.A. (Supervisor)

Prof. Dr. Kirsten Legerlotz

Prof. Dr. Matthias Wilhelm Hoppe

Dedicated to my parents

Karin & Shahriar

Reading notes

Dear reader, the following text is the result of a lot of work and especially passion for health. Because of the different stories and events in my life that affect health in various aspects, it is a real pleasure for me to work in this field. I have learned a lot, and this dissertation is a return for that. I hope you enjoy reading it and make good use of the concepts covered and developed.

The present dissertation comprises the following sections: a general introduction, three original publications, a general discussion, and a final summary with conclusions. The publications are included in the versions that have been accepted for publication. While the contents remain the same, the numbering of the tables and figures differs from the original publications due to the adopted format. Additionally, the references in the tables and figures are numbered according to the sequence in which they appear in their respective chapters. The general introduction and discussion serve as supplementary materials to provide a meta-perspective.

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List of abbreviations

B

BMI	Body Mass Index

C

CL	Carried load

E

EE	Energy expenditure
EU	European Union

G

GPAQ	Global physical activity questionnaire

H

HR	Heart rate

I

IGLO	Individual, group, leader, organization

M

MET	Metabolic Equivalent
MCS	Mental Component Summary
MVPA	moderate-to-vigorous physical activity

P

PCS	physical Component Summary
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses

R

RCT	Randomised controlled trials
RER	Respiratory exchange ratio
RoB	Risk-of-bias-tool

S

SF-36	Short Form Health Survey-36

V

VAS	visual analogue scale
VCO_2	carbon dioxide release
VE	Total ventilation
VO_2	oxygen uptake

W

WHO	World Health Organisation

General introduction

This chapter provides an overview of workplace health promotion for industrial workers. First, the development of the industrial worker and sector is presented. Next, the development of workplace health promotion is described. After that, the challenges arising from these developments and the resulting need for targeted health interventions are discussed. Finally, the superior aims and motivation of the present dissertation are highlighted.

Industrial workers

Industrial workers form the backbone of many economies around the world and remain one of the three largest economic sectors in the European Union (EU) [1]. Notably, around 20% of workers in industrial countries are engaged in shift work, which is expected to rise [2]. The industrial sector remains male-dominated, with around 80% of the construction and industrial sector workers being men [3]. Moreover, the structure of companies within this sector is diverse: 16% are micro-enterprises, 45% are small to medium-sized companies, and 39% are large enterprises [1].

Industrial workers are defined as individuals engaged in manual labor within manufacturing [4] or construction settings [5]. This group is distinct from other occupational groups, as their work is predominantly characterized by highly physically demanding tasks, often involving repetitive movements and high-force exertion [6-8]. Furthermore, these workers face significant exposure to environmental hazards such as noise, vibrations, or chemical substances [9-12]. Despite these commonalities, work characteristics and specific task characteristics can vary between sectors, with production work facing unique challenges driven by technological and innovative changes [13].

The evolution of industrial labor began with the Industrial Revolution, which introduced mechanization and fundamentally reshaped production systems [14]. This led to environmental changes and the emergence of repetitive manual tasks, which are forming the basis of modern industrial work [15]. These transformations in labor practices continue to evolve through technological innovations, such as automation and robotics, which have redefined the industrial landscape and increased the demand for skilled workers to manage and operate advanced machinery [16, 17]. While these innovations have led to substantial productivity gains, they also raise challenges for workers, particularly regarding health risks and the need for adaptation to changing work environments [18-20].

The health of industrial workers has emerged as a critical global concern [21-24]. The demanding nature of industrial work imposes significant strain, contributing to elevated rates of chronic diseases, work-related musculoskeletal disorders, and functional limitations [24]. Notably, work-related musculoskeletal disorders are characterized by high prevalence and persistence despite low incidence rates [12, 25, 26]. For instance, in 2019, over 50% of manufacturing workers in the EU reported absences due to work-related musculoskeletal disorders, exceeding those caused by flu-related absences [25, 27]. Thus, these disorders affect workers' physical capabilities and hinder long-term participation in the labor market [1].

Chronic diseases and functional limitations profoundly impact the quality of life of industrial workers [28], affecting their physical capabilities, mental well-being, and overall performance [29]. These health challenges also carry significant economic implications. Absenteeism, productivity losses, and treating chronic diseases among industrial workers result in substantial costs [30].

Beyond physical demands, industrial workers face various psychological stressors, including shift schedules [31, 32], task monotony [33], time pressure [4], and limited job control [34, 35]. These factors have been linked to increased risks of mental health disorders, further compounding the health burden of this workforce [29, 36, 37]. These demands create a multidimensional burden on the health of industrial workers [38, 39].

These health concerns are occurring against the backdrop of globalization, the digital revolution, and demographic changes, which are reshaping the industrial workforce, employment levels, job responsibilities, and working conditions [1, 15]. Despite this, these workers are closely linked to the socioeconomic status of this workforce, including lower incomes, limited educational attainment, and restricted occupational mobility, which collectively exacerbate health disparities [24, 40].

Workplace Health Promotion

Addressing the health challenges of industrial workers highlights the importance of workplace health promotion in improving workers' health, well-being, and productivity [41, 42]. By targeting individual and organizational health concerns, workplace health promotion aims to improve morale, enhance productivity, reduce absenteeism, and lower healthcare costs [43, 44].

Therefore, businesses increasingly view workplace health promotion as a strategic investment, aiming to reduce workplace risks, boost efficiency, elevate product and service quality, and enhance their corporate image [45], ultimately contributing to improved productivity [41].

Workplace health promotion is defined as the combined efforts of employers, employees, and society to improve the health and well-being of people at work [46]. Workplaces provide a central setting for health initiatives, offering a unique opportunity to reach diverse socioeconomic groups and address disparities [47-49].

Workplace health promotion stems from the Ottawa Charter 1986, which shifted focus to structural health determinants and supportive environments [50]. Adapted for workplaces, it emphasized creating supportive environments and integrating health promotion into corporate policies [45]. In Germany, workplace health promotion increased in the late 20th century, influenced by European concepts like workers' medicine and the Scandinavian democracy at work model [45, 51]. The 1988 Health Reform Act (§20 SGB V) established a legal framework, followed by the 1995 European Network of Workplace Health Promotion (ENWHP) and the Luxembourg Declaration, emphasizing systematic health strategies, goal-oriented approaches, and the economic value of employee well-being [52, 53]. Mandatory health promotion services began in 2007, with the 2015 Prevention Act further prioritizing prevention alongside rehabilitation and care [53]. Recent efforts in Germany highlight economic benefits, presenting health management as a strategic business priority [54, 55].

Workplace health promotion programs include interventions such as ergonomic improvements, flexible work schedules, or behavioral approaches [8, 29, 56, 57]. Effective implementation requires collaboration across departments, including human resources and occupational health teams, ensuring initiatives align with organizational goals while addressing employee needs [45]. Proactively addressing workplace risks and physical demands through assessments of workload and expenditure is crucial for developing targeted health strategies [6, 58].

Research Deficit and Objective of the Dissertation

Despite growing awareness of industrial workers' health challenges, research on targeted, evidence-based workplace health promotion remains insufficient [40]. This dissertation addresses this gap by combining three complementary studies that together provide a multifaceted understanding of industrial workers' health and offer a foundation for more tailored and sustainable health promotion strategies.

The dissertation employs a three-step approach. First, a systematic review synthesizes current evidence on health programs for industrial workers, identifying gaps and informing subsequent studies. Building on these findings, two empirical studies examine environmental factors and health determinants, focusing on organizational and job-related conditions influencing workers' well-being.

This research investigates the effectiveness of workplace health promotion interventions for industrial workers and explores how the innate human capacities for flexibility, compensation, and adaptation manifest in challenging industrial environments. The findings are discussed in relation to their implications for workplace health strategies and sustainable workforce management.

By highlighting the dynamic interplay between flexibility, compensation, and adaptation [59], this dissertation offers valuable evidence for designing tailored, sustainable workplace health promotion with a human-centered approach.

Publication 1: Effectiveness of workplace health promotion programs for industrial workers: A systematic review

Workplace health promotion programs play a crucial role in improving workers' health and productivity by integrating behavioral, organizational, and safety-based interventions [60-68]. These initiatives cultivate supportive workplaces, promote health behaviors, and achieve improved productivity, reduced absenteeism, and lower healthcare costs [41, 43].

The health of industrial workers is a global concern due to their heightened risk of chronic diseases and functional limitations driven by socio-economic factors and demanding work conditions [21-24, 29, 36, 37, 69-72].

Despite the significant health risks faced by industrial workers, evidence of the effectiveness of workplace health promotion programs tailored to this population remains fragmented [28, 73-75]. To address this gap, high-quality evidence is needed to assess the effectiveness of interventions and provide targeted recommendations for improving health outcomes in industrial workers.

The study synthesized the available evidence on the effectiveness of workplace health promotion programs targeting industrial workers. Through a systematic review, this study assessed health outcomes, identified effective intervention types (behavioral, organizational, safety, and multi-component), and evaluated the quality of evidence. The findings aim to inform the development of effective workplace health promotion strategies tailored to industrial workers.

Publication 2: Impact of work pace on cardiorespiratory outcomes, perceived effort, and carried load in industrial workers: A randomized cross-over trial

Industrial workers are exposed to physical hazards during work, including heavy lifting, awkward positions, vibrations, high temperatures, precision, noise, excessive work pace, and repetitive work, potentially leading to long-term health consequences [6, 11]. Over 60% of industrial workers perform repetitive movements with cycle times under 30 seconds and little variation [76]. However, experimental evidence on the acute effects of work pace on physiological outcomes is limited [77-80].

The impact of work pace on cardiorespiratory factors has not been thoroughly examined yet. Comprehensive evaluations are essential to develop targeted health strategies that address the specific challenges faced by industrial workers, thereby enhancing the long-term effectiveness of workplace health initiatives [42].

The second study investigated the impact of work paces on cardiorespiratory factors, perceived effort, and carried the load in industrial workers through a randomized cross-over trial. The findings aim to provide insights into the physiological and subjective implications of work pace, contributing to better workplace health promotion practices.

Publication 3: Work conditions and determinants of health status among industrial shift workers: A cross-sectional study

Industrial work is recognized as one of the most physically demanding and mentally challenging occupational sectors [7]. Beyond the physical demands, workers are frequently exposed to various occupational hazards, which affect workers health, increasing risk of illnesses, injuries, and chronic diseases.

A proactive approach to workplace health promotion is essential for improving worker health and productivity by addressing factors influencing well-being. Early detection of external health determinants is critical for timely diagnosis and preventive care, yielding long-term benefits.

Standardized health promotion programs frequently overlook the intricacies of industrial work settings. Past studies indicate that a universal approach might be overly simplistic, and health interventions need to account for the varied working conditions and health disparities present in industrial sectors. Making distinctions based on working conditions could offer a useful strategy for evaluating health-related factors.

This cross-sectional study evaluated how varying working conditions among industrial workers affect health outcomes. The results intend to assist stakeholders in creating customized promotion strategies that meet the distinct needs of the workforce.

References

1. Parent-Thirion, A., et al., *Sixth European working conditions survey–overview report.* 2016.
2. Khosravipour, M., et al., *A systematic review and meta-analysis of the association between shift work and metabolic syndrome: The roles of sleep, gender, and type of shift work.* Sleep Med Rev, 2021. **57**: p. 101427.
3. Hanna, E., B. Gough, and S. Markham, *Masculinities in the construction industry: A double-edged sword for health and wellbeing?* Gender, Work & Organization, 2020. **27**(4): p. 632-646.
4. Berlin, C., et al. *A Systemic Overview of Factors Affecting the Cognitive Performance of Industrial Manual Assembly Workers*. in *Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021)*. 2021. Cham: Springer International Publishing.
5. Macias, E., et al., *Fourth European Working Conditions Survey*. 2007.
6. Dias, M., et al., *Cardiovascular load assessment in the workplace: A systematic review.* International Journal of Industrial Ergonomics, 2023. **96**: p. 103476.
7. Ranasinghe, U., et al., *A systematic review on workplace health and safety of ageing construction workers.* Safety Science, 2023. **167**: p. 106276.
8. Anagha, R., *A Review on Ergonomic Risk Factors Causing Musculoskeletal Disorders among Construction Workers.* International Journal of Engineering Research and, 2020. **V9**(06).
9. Hasle, P., C. Uhrenholdt Madsen, and D. Hansen, *Integrating operations management and occupational health and safety: A necessary part of safety science!* Safety Science, 2021. **139**: p. 105247.
10. Themann, C.L. and E.A. Masterson, *Occupational noise exposure: A review of its effects, epidemiology, and impact with recommendations for reducing its burden.* The Journal of the Acoustical Society of America, 2019. **146**(5): p. 3879-3905.
11. Wang, D., F. Dai, and X. Ning, *Risk Assessment of Work-Related Musculoskeletal Disorders in Construction: State-of-the-Art Review.* Journal of Construction Engineering and Management, 2015. **141**(6): p. 04015008.
12. He, X., et al., *Prevalence of work-related musculoskeletal disorders among workers in the automobile manufacturing industry in China: a systematic review and meta-analysis.* BMC Public Health, 2023. **23**(1): p. 2042.
13. Rosen, P.H. and S. Wischniewski, *Scoping review on job control and occupational health in the manufacturing context.* The International Journal of Advanced Manufacturing Technology, 2019. **102**(5-8): p. 2285-2296.
14. Lieberman, D., *The story of the human body: evolution, health, and disease*. 2014: Vintage.
15. Warhurst, C., et al., *Upward convergence in working conditions*. 2019: Publications Office of the European Union.
16. Iranzo, S., et al., *Ergonomics assessment of passive upper-limb exoskeletons in an automotive assembly plant.* Appl Ergon, 2020. **87**: p. 103120.
17. Sorensen, G., et al., *The future of research on work, safety, health and wellbeing: A guiding conceptual framework.* Soc Sci Med, 2021. **269**: p. 113593.
18. Wei, W. and L. Li, *The Impact of Artificial Intelligence on the Mental Health of Manufacturing Workers: The Mediating Role of Overtime Work and the Work Environment.* Frontiers in Public Health, 2022. **10**.

19. Capponi, M., et al., *Assembly complexity and physiological response in human-robot collaboration: Insights from a preliminary experimental analysis.* Robotics and Computer-Integrated Manufacturing, 2024. **89**: p. 102789.
20. Brunzini, A., et al., *A Preliminary Experimental Study on the Workers' Workload Assessment to Design Industrial Products and Processes.* Applied Sciences, 2021. **11**: p. 12066.
21. Campbell, M.K., et al., *Tailoring and targeting a worksite health promotion program to address multiple health behaviors among blue-collar women.* Am J Health Promot, 2000. **14**(5): p. 306-13.
22. Hoffmann, C., G. Stassen, and A. Schaller, *Theory-Based, Participatory Development of a Cross-Company Network Promoting Physical Activity in Germany: A Mixed-Methods Approach.* Int J Environ Res Public Health, 2020. **17**(23).
23. Minna, S. and N. Mika, *Relationship between construction workers' musculoskeletal disorders and occupational health service activities.* Work, 2012. **41** Suppl 1: p. 3753-6.
24. Quilling, E., et al., *State of evidence on municipal strategies for health promotion and prevention: a literature and database research (Scoping Review).* BMC Public Health, 2022. **22**(1): p. 301.
25. Govaerts, R., et al., *Prevalence and incidence of work-related musculoskeletal disorders in secondary industries of 21st century Europe: a systematic review and meta-analysis.* BMC Musculoskelet Disord, 2021. **22**(1): p. 751.
26. Umer, W., et al., *The prevalence of musculoskeletal symptoms in the construction industry: a systematic review and meta-analysis.* Int Arch Occup Environ Health, 2018. **91**(2): p. 125-144.
27. Cimarras-Otal, C., et al., *Adapted exercises versus general exercise recommendations on chronic low back pain in industrial workers: A randomized control pilot study.* Work, 2020. **67**(3): p. 733-740.
28. Sundstrup, E., et al., *A Systematic Review of Workplace Interventions to Rehabilitate Musculoskeletal Disorders Among Employees with Physical Demanding Work.* J Occup Rehabil, 2020. **30**(4): p. 588-612.
29. Torquati, L., et al., *Shift Work and Poor Mental Health: A Meta-Analysis of Longitudinal Studies.* Am J Public Health, 2019. **109**(11): p. e13-e20.
30. Baase, C.M., *Auswirkungen chronischer Krankheiten auf Arbeitsproduktivität und Absentismus und daraus resultierende Kosten für die Betriebe*, in *Fehlzeiten-Report 2006: Chronische Krankheiten*, B. Badura, H. Schellschmidt, and C. Vetter, Editors. 2007, Springer Berlin Heidelberg: Berlin, Heidelberg. p. 45-59.
31. Boivin, D.B. and P. Boudreau, *Impacts of shift work on sleep and circadian rhythms.* Pathol Biol (Paris), 2014. **62**(5): p. 292-301.
32. Jelmini, J.D., et al., *The effect of extended shift work on autonomic function in occupational settings: A systematic review and meta-analysis.* J Occup Health, 2023. **65**(1): p. e12409.
33. Cham, B.S., et al., *Investigating the joint effects of overload and underload on chronic fatigue and wellbeing.* Work & Stress, 2021. **35**(4): p. 344-357.
34. Cheng, S. and Y. Wang, *The impact of perceived environmental competitiveness on employee mental health: a moderated mediation model of job crafting and work–family conflict.* Frontiers in Public Health, 2024. **12**.
35. Estudillo, B., et al., *The role of organizational factors in promoting workers' health in the construction sector: A comprehensive analysis.* J Safety Res, 2024. **88**: p. 41-55.
36. Yang, S., et al., *Transformation to Industrial Artificial Intelligence and Workers' Mental Health: Evidence From China.* Front Public Health, 2022. **10**: p. 881827.

37. Saulle, R., et al., *Shift work, overweight and obesity in health professionals: a systematic review and meta-analysis.* Clin Ter, 2018. **169**(4): p. e189-e197.
38. Abrar, A., et al., *Health status assessment of workers during construction phase of highway rehabilitation projects around lahore, Pakistan.* J Occup Health, 2017. **59**(1): p. 74-80.
39. Nguyen, T.T., et al., *Factors correlated with neuropathic pain among industrial workers in Vietnam: a multi-site cross-sectional study.* Frontiers in Public Health, 2023. **11**.
40. Robroek, S.J., P. Coenen, and K.M. Oude Hengel, *Decades of workplace health promotion research: marginal gains or a bright future ahead.* Scandinavian Journal of Work, Environment & Health, 2021(8): p. 561-564.
41. Burton, J. and W.H. Organization, *WHO healthy workplace framework and model: Background and supporting literature and practices*. 2010: World Health Organization.
42. Cancelliere, C., et al., *Are workplace health promotion programs effective at improving presenteeism in workers? A systematic review and best evidence synthesis of the literature.* BMC Public Health, 2011. **11**: p. 395.
43. Bertera, R.L., *The effects of workplace health promotion on absenteeism and employment costs in a large industrial population.* Am J Public Health, 1990. **80**(9): p. 1101-5.
44. Soler, R.E., et al., *A systematic review of selected interventions for worksite health promotion. The assessment of health risks with feedback.* Am J Prev Med, 2010. **38**(2 Suppl): p. S237-62.
45. Masanotti, G. and L. Briziarelli, *The evolution of workplace health promotion in Europe: the Italian case.* J Prev Med Hyg, 2006. **47**(2): p. 37-41.
46. Šidagytė, R., et al., *The legislative backgrounds of workplace health promotion in three European countries: a comparative analysis.* J Occup Med Toxicol, 2015. **10**: p. 18.
47. Amatori, S., et al., *Short High-Intensity Interval Exercise for Workplace-Based Physical Activity Interventions: A Systematic Review on Feasibility and Effectiveness.* Sports Med, 2023. **53**(4): p. 887-901.
48. Grimani, A., E. Aboagye, and L. Kwak, *The effectiveness of workplace nutrition and physical activity interventions in improving productivity, work performance and workability: a systematic review.* BMC Public Health, 2019. **19**(1): p. 1676.
49. Moreira-Silva, I., et al., *The Effects of Workplace Physical Activity Programs on Musculoskeletal Pain: A Systematic Review and Meta-Analysis.* Workplace Health Saf, 2016. **64**(5): p. 210-22.
50. WHO, *Ottawa charter for health promotion, 1986*. 1986, World Health Organization. Regional Office for Europe.
51. Ilmarinen, J., *From Work Ability Research to Implementation.* International Journal of Environmental Research and Public Health, 2019. **16**(16): p. 2882.
52. Promotion, E.N.W.H., *Luxembourg declaration on workplace health promotion in the European Union*. 1997: Bundesanstalt für Arbeitschutz und Arbeitsmedizin.
53. Kuhn, K., *Der Betrieb als gesundheitsförderndes Setting: Historische Entwicklung der Betrieblichen Gesundheitsförderung*, in *Lehrbuch Betriebliche Gesundheitsförderung*, G. Faller, Editor. 2017, Hogrefe: Bern. p. 39-56.
54. Lutz, N., et al., *Cost-effectiveness and cost-benefit of worksite health promotion programs in Europe: a systematic review.* Eur J Public Health, 2019. **29**(3): p. 540-546.

55. Faller, G., *Future Challenges for Work-Related Health Promotion in Europe: A Data-Based Theoretical Reflection.* International Journal of Environmental Research and Public Health, 2021. **18**(20): p. 10996.
56. Shin, S.J. and W.G. Yoo, *Effect of workstation height and distance on upper extremity muscle activity during repetitive below-the-knee assembly work.* J Occup Health, 2015. **57**(2): p. 193-6.
57. Short, M.A., et al., *A systematic review of the sleep, sleepiness, and performance implications of limited wake shift work schedules.* Scand J Work Environ Health, 2015. **41**(5): p. 425-40.
58. Poulianiti, K.P., G. Havenith, and A.D. Flouris, *Metabolic energy cost of workers in agriculture, construction, manufacturing, tourism, and transportation industries.* Ind Health, 2019. **57**(3): p. 283-305.
59. Mulder, T., *Das adaptive Gehirn: über Bewegung, Bewusstsein und Verhalten*. 2007: Georg Thieme Verlag.
60. Prall, J. and M. Ross, *The management of work-related musculoskeletal injuries in an occupational health setting: the role of the physical therapist.* J Exerc Rehabil, 2019. **15**(2): p. 193-199.
61. Conn, V.S., et al., *Meta-analysis of workplace physical activity interventions.* Am J Prev Med, 2009. **37**(4): p. 330-9.
62. Kuster, A.T., et al., *Computer-based versus in-person interventions for preventing and reducing stress in workers.* Cochrane Database Syst Rev, 2017. **8**(8): p. Cd011899.
63. Freak-Poli, R., et al., *Workplace pedometer interventions for increasing physical activity.* Cochrane Database Syst Rev, 2020. **7**(7): p. CD009209.
64. Botwright, S., et al., *Which interventions for alcohol use should be included in a universal healthcare benefit package? An umbrella review of targeted interventions to address harmful drinking and dependence.* BMC Public Health, 2023. **23**(1): p. 382.
65. La Torre, G., et al., *Smoking cessation interventions on health-care workers: a systematic review and meta-analysis.* PeerJ, 2020. **8**: p. e9396.
66. Hakro, S. and L. Jinshan, *Workplace Employees' Annual Physical Checkup and During Hire on the Job to Increase Health-care Awareness Perception to Prevent Disease Risk: A Work for Policy-Implementable Option Globally.* Saf Health Work, 2019. **10**(2): p. 132-140.
67. Padula, R.S., et al., *Job rotation designed to prevent musculoskeletal disorders and control risk in manufacturing industries: A systematic review.* Applied Ergonomics, 2017. **58**: p. 386-397.
68. Smith, S.D., *Safety first? Production pressures and the implications on safety and health.* Construction Management and Economics, 2019. **37**(4): p. 238-242.
69. Chaiklieng, S. and P. Suggaravetsiri, *Low Back Pain (LBP) Incidence, Ergonomics Risk and Workers' Characteristics in Relations to LBP in Electronics Assembly Manufacturing.* Indian J Occup Environ Med, 2020. **24**(3): p. 183-187.
70. Sjogaard, G., et al., *The elixir of muscle activity and kinesiology in a health perspective: Evidence of worksite tailored exercise training alleviating muscle disorders.* J Electromyogr Kinesiol, 2021. **61**: p. 102600.
71. Buchvold, H.V., et al., *Associations between night work and BMI, alcohol, smoking, caffeine and exercise--a cross-sectional study.* BMC Public Health, 2015. **15**: p. 1112.
72. Manoogian, E.N.C., et al., *Feasibility of time-restricted eating and impacts on cardiometabolic health in 24-h shift workers: The Healthy Heroes randomized control trial.* Cell Metab, 2022. **34**(10): p. 1442-1456 e7.
73. Pega, F., et al., *Monitoring workers' health: focus on rights, determinants, and equity.* Lancet, 2023. **402**(10410): p. 1306-1308.

74. Montano, D., H. Hoven, and J. Siegrist, *A meta-analysis of health effects of randomized controlled worksite interventions: does social stratification matter?* Scand J Work Environ Health, 2014. **40**(3): p. 230-4.
75. Brierley, M.L., et al., *The Effectiveness of Sedentary Behaviour Reduction Workplace Interventions on Cardiometabolic Risk Markers: A Systematic Review.* Sports Med, 2019. **49**(11): p. 1739-1767.
76. Santos, J., et al., *The influence of task design on upper limb muscles fatigue during low-load repetitive work: A systematic review.* International Journal of Industrial Ergonomics, 2016. **52**: p. 78-91.
77. Gooyers, C.E. and J.M. Stevenson, *The impact of an increase in work rate on task demands for a simulated industrial hand tool assembly task.* International Journal of Industrial Ergonomics, 2012. **42**(1): p. 80-89.
78. Januario, L.B., et al., *Can exposure variation be promoted in the shoulder girdle muscles by modifying work pace and inserting pauses during simulated assembly work?* Appl Ergon, 2018. **66**: p. 151-160.
79. Lee, W., et al., *Physiological responses, trunk posture, and work pace in commercial building cleaning in Washington State: An observational field study.* J Safety Res, 2023. **86**: p. 107-117.
80. Mathiassen, S.E. and J. Winkel, *Physiological comparison of three interventions in light assembly work: reduced work pace, increased break allowance and shortened working days.* Int Arch Occup Environ Health, 1996. **68**(2): p. 94-108.

Publication 1: Effectiveness of Workplace Health Promotion Programs for Industrial Workers: A Systematic Review

Sasha Javanmardi[1], Ludwig Rappelt[1,2], Sascha Zangenberg[1], Lars Heinke[1], Christian Baumgart[1], Daniel Niederer[1,3], Jürgen Freiwald[1]

[1] Department of Movement and Training Science, University of Wuppertal, Wuppertal, Germany

[2] Department of Intervention Research in Exercise Training, German Sport University Cologne, Cologne, Germany

[3] Institute of Occupational, Social and Environmental Medicine, Goethe University Frankfurt, Frankfurt, Germany

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Abstract

Background: Workplace health promotion is essential for individual and organisational well-being and disease prevention, also in industrial workers. As the transfer of the evidence on the effectiveness of such programs into practice is limited due to scattered effects, the need for a consolidation of the available studies is given. The purpose of this systematic review was to synthesise the evidence on the effectiveness of workplace health promotion programs for industrial workers.

Methods: An electronic literature search was conducted in PubMed, Cochrane Library, Web of ScienceTM, Scopus, and EBSCOHost until July 26th 2023. Studies investigated industrial workers who performed manual labour for at least 20 hours per week were included. They had to receive a workplace health promotion intervention under any control condition. Outcomes were workplace health interventions' safety and corresponding health-related outcomes. The revised Cochrane risk-of-bias assessed the risk of bias (Rob 2) tool for randomised control trials (RCT) and cluster RCT. Quality assessment was performed using a modified Downs and Black Checklist.

Results: Of the 25,555 studies initially identified, 39 were included. Generally, the mean quality of the studies was moderate, with most studies judged with a high overall risk of bias. Twenty-seven studies employed a behavioural approach, while one study adopted an organisational one. Ten studies utilised a multicomponent approach, and one intervention improved safety outcomes. The analysis of the results indicated an overall positive but heterogeneous effect across the different approaches.

Conclusions: The studies included in this review provide evidence that workplace health promotion can be effective. However, the overall findings are inconclusive due to the high risk of bias. Therefore, the results should be interpreted cautiously. Despite the considerable amount of research conducted in this field, additional well-designed studies are needed to fully confirm the effectiveness and determine the most promising types of interventions for improving and maintaining industrial health.

Keywords

occupational health, systematic review, methodological quality, evidence-based practice, blue-collar workers, wellbeing

Background

Workplace health promotion programs aim to influence the workers' health and productivity [1]. These programs encompass a range of activities designed to support and improve health among employees, including behavioural [2-7], organisational [8, 9], and safety interventions [10]. Their collective goal is to establish a healthy work environment and encourage positive health behaviours among employees [11]. There has been a notable surge in interest in recent years, indicating a growing recognition [12]. Given the substantial amount of time individuals devote to their jobs, the workplace offers a prime opportunity for health-enhancing initiatives [13]. Moreover, it can reach people of different socioeconomic statuses [14]. By addressing health concerns at both the individual and organisational levels, these programs aim to create a comprehensive approach to workplace health [11]. Recognising that investing in employee health can positively impact morale, productivity, absenteeism rates, and healthcare costs [15] underscores the importance of such programs in the modern workplace.

The health of blue-collar workers, including industrial workers, is a global concern [16-18]. Industrial workers are at a higher risk of developing chronic diseases or experiencing functional limitations owing to their low incomes, occupational status, and educational levels [19]. Previous studies have shown that the physical demands of work in an industrial setting can pose risks to workers' health from a physical [18, 20-23] and psychological standpoint [24-26].

Despite the significant impact of occupational hazards on the health and well-being of industrial workers [27], comprehensive, evidence-based guidelines for preventing and managing these conditions are lacking. Research suggests that workplace health promotion effectively reaches out to workers, but it is still challenging to extend these efforts because of shift work and workers who have yet to report any health-related issues [28]. A growing number of systematic reviews and meta-analyses emerged in the field of workplace health promotion [29-31]. However, these analyses do not distinguish between the different populations. The evidence on the effectiveness of such programs in practice is further limited due to scattered effects. To the best of our knowledge, no review specifically addresses industrial workers. Conclusively, the purpose of our systematic review was to investigate the evidence on the effectiveness of workplace health promotion programs specifically for industrial workers. The objectives were to assess the effectiveness of workplace health promotion programs in improving health outcomes among industrial workers, identify effective interventions (behavioural, organisational, and safety), evaluate the quality of evidence, and determine the gaps in the current evidence.

Methods

Research Design and Search Strategy

This systematic review was pre-registered in PROSPERO (CRD42023445044). An electronic literature search was conducted using the following recommended databases: PubMed, Cochrane Library, Web of Science, Scopus, EMBASE(assessed via Cochrane), CINAHL (assessed via Cochrane), and EBSCOHost [32, 33]. The search strings and strategy used are listed in Table 1. The strings were adjusted for database-specific truncations, wildcards, and proximity operators. Articles were retrieved from the earliest possible date until July 26, 2023.

Table 1: Search strings and strategy

Variable	Search string
Physical activity	physical activity OR exercise OR training
Industrial workers	blue-collar workers OR factory workers OR manufacturing workers OR construction workers OR industrial workers
Health promotion	health OR health promotion OR occupational health promotion OR public health OR workplace health

To increase the sensitivity of the literature search, we expanded our search by manually searching grey literature and using Google Scholar to locate articles not found in major electronic databases. We searched for articles using the terms "workplace health promotion" combined with "blue-collar workers", "industrial workers", or "manufacturing workers". The reference lists of the included studies were also checked to identify additional eligible studies. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) were used to follow this process [34].

Study eligibility criteria

The following criteria were established for screening titles and abstracts by three independent investigators:

- Randomised controlled trials (RCT); with parallel-group, cluster-randomised or crossover design
- Articles written in English.
- Exclusion of animal studies and articles focused on injured population
- No systematic reviews or meta-analyses
- Interventions related to workplace health promotion and the safety of industrial workers

Inclusion and Exclusion Criteria

The search strings were determined using the Population, Intervention, Comparisons, and Outcomes (PICO) scheme. Included populations were industrial workers of both sexes aged 18-67 years who worked at least 20 hours a week in industry or manufacturing and were active for at least six months. "Industrial workers" were defined as people who perform manual labour in a manufacturing setting [35]. Any interventions conducted in the workplace, either during working hours or shortly before or after work, were included with any passive and/or active controls and comparators. The main outcomes of interest were the different dimensions of occupational health and safety according to the WHO definition [11]. These outcomes included health-related outcomes, covering physical, mental, social, behavioural, and physiological domains, as well as other outcomes, such as work-related outcomes.

The identified studies were downloaded using a citation manager (Clarivate Analytics, EndNote 20.5, London, UK). After removing any duplicates, the studies were transferred to Rayyan [36]. Using the Prospero protocol, the eligibilities of the titles and abstracts were examined before the full text was evaluated. Two independent investigators (SJ and SZ) executed the methodological process, and a third investigator (LR) resolved any discrepancies.

Evaluating the risk of bias

The revised Cochrane risk-of-bias tool (RoB2) was used to evaluate all included studies [37]. The tool addresses biases categorised into five domains: (1) the randomisation method, (2) deviations from predesignated interventions, (3) the absence of outcome data, (4) outcome measurement, and (5) selective reporting of findings. RoB2 for cluster RCTs was utilised, which additionally assesses the timing of identification or recruitment of participants as risk of bias [38]. An overall risk of bias domain was built based on the individual judgements; all outcomes with at least one high risk for a certain bias received an overall rating of "high risk". Each domain is judged as 'low risk of bias', 'some concerns', or 'high risk of bias' [37]. Two investigators (SJ and LR) independently assessed the risk of bias. In case of disagreements, a third investigator (SZ) was consulted. The data was visualised with risk-of-bias VISualization in R [39].

Methodological Study Quality Assessment

To evaluate scientific precision at the individual study level, a critical appraisal was independently performed by two investigators (SJ and SZ) using a modified version of the Downs and Black checklist [40]. This checklist for controlled studies includes 27 questions on internal validity, external validity, and power. Notably, item 27 was modified based on the presence of a power calculation, with a maximum score of 1 (a power analysis was performed) or 0 (absence of a power analysis). The highest attainable score on the checklist was 28 (instead of 32). The investigators' results were compared, and potential disagreements were resolved by consensus. The final assessment of the quality of each study was calculated as a percentage, with a higher percentage reflecting greater quality. Consistent with previous recommendations [41], the ratings for each study were classified as low (≤33.3%), moderate (33.4–66.7%), or high (≥66.8%).

Data extraction and evidence synthesis

One investigator (SJ) analysed the studies using the PICO scheme: (1) Participants = number of participants, sex, age, and working environment; (2) Intervention = type and dose (duration, time, intensity, frequency) of the intervention; (3) Comparators = type and dose (duration, time, intensity, frequency) of the control/comparator group; and (4) Outcomes = health-related outcomes. A second investigator (SZ) controlled the data extraction. Statistical interpretation of the results was provided only if the results were reported in the original study.

The interventions of the included studies were subsequently divided into categories of different workplace health promotion approaches or the category workplace health and safety [42]: Interventions to ensure workplace health and safety are based on department guidelines aimed at protecting workers from specific workplace risks (e.g., accidents, substance exposure, or noise) [42]. In the different workplace health promotion categories, the studies were classified into worker-directed approaches, called behavioural or work-directed approaches, called organisational approaches [43]. In addition, studies that used variable combinations were classified as multicomponent studies.

Due to the heterogeneity of outcomes and interventions of the studies, no meta-analysis could be performed. Instead, we provide a systematic narrative synthesis of the findings using the guidance of Popay and colleagues [44].

Results

Literature search

Figure 1 provides the PRISMA flow diagram of the complete search process. Finally, 39 studies [45-83] were included in this systematic review.

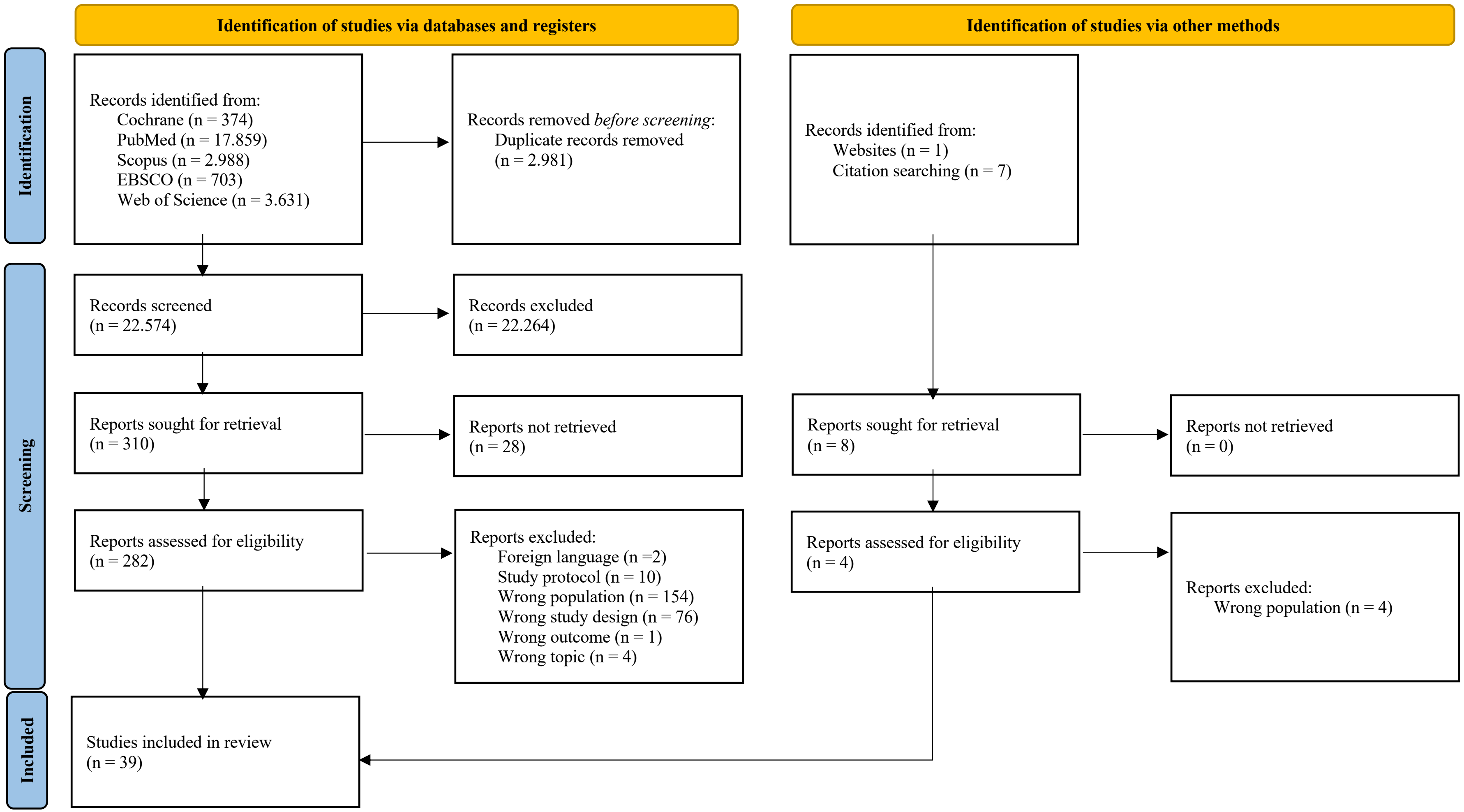

Figure 1: PRISMA flow diagram

Description and characteristics of the included studies

The included studies are summarised in Table 2. All studies provided comprehensive data, eliminating the need to contact authors for further information. The studies were conducted across five continents and 18 countries, most of which were from Denmark (n=9; [46, 48, 55, 56, 73-75, 81, 82]), the USA (n=5; [47, 49, 59, 60, 78]), and Iran (n=4; [45, 58, 64, 66]). The publication dates ranged between 1997 and 2023, with the majority (72%) published in the last decade.

The investigated populations mainly focused on assembly line workers (n=6 [51, 57, 60, 64, 68, 69]), followed by industrial (n=5 [54, 58, 63, 70, 72]), manufacturing (n=5 [50, 56, 65, 79, 80]), and general factory workers (n=4 [45, 62, 66, 67]). The age of the participants ranged from 17 to 65 years, with samples ranging from 24 [67] to 3,479 [79, 80] (mean: 310; median: 91), representing a total of 10,215 industrial workers with 5,606 investigated males, 3,457 females, and 1,152 workers without an exact designation of sex. Twelve studies investigated only males [47, 48, 50, 54, 55, 63, 64, 66, 69, 78, 81, 82], 6 studies only females [49, 61, 68, 72, 76, 83], and 14 both sexes [46, 51, 52, 56, 58, 59, 65, 70, 71, 73-75, 79, 80]. Twenty-seven studies examined behavioural changes [45, 46, 48, 50, 51, 53-55, 57-62, 65, 67-70, 72-76, 81-83], one study examined organisational changes [52], 10 studies examined multicomponent interventions [47, 49, 56, 63, 64, 66, 71, 77, 79, 80], and one study provided safety data [78].

Most interventions lasted three to six months (see Table 2). Seven studies [47-49, 61, 66, 77, 78] reported a post-intervention follow-up between 3 and 12 months.

The control groups in the studies received various interventions, including general treatment [46, 47, 57, 62, 65, 67, 70, 71, 73-75], educational sessions [49, 55, 66, 79-82], recommendations [48, 51, 59], recommendations with feedback [83], and ergonomic training [52]. In most studies, the control group received no interventions [45, 50, 53, 54, 56, 58, 60, 61, 63, 64, 68, 69, 72, 76-78].

The studies used various outcome measures to assess workplace health promotion, with 19 using only subjective measures [45-47, 49, 53, 56, 58, 60, 61, 64-67, 75-78, 80, 83], six only objective measures [54, 71, 72, 74, 79, 81], and 14 employing both measures [48, 50-52, 55, 57, 59, 62, 63, 68-70, 73, 82] (see table 2). Seventeen studies examined health- and work-related outcomes [48, 52, 54-57, 59, 61, 70, 72, 75, 77-79, 81-83], 19 reported physical health-related outcomes [48, 49, 51, 55-57, 60, 62, 63, 67-70, 72-74, 77, 81, 82], 10 reported mental health-related outcomes [46, 48, 50, 52, 56, 58, 61, 67, 70, 76], and three reported social health-related outcomes [46, 58, 74]. Furthermore, six studies examined physiological parameters [50, 62, 63, 70, 76, 81], and 19 examined musculoskeletal disorder parameters [45, 48, 51-53, 57, 60, 62, 64, 65, 67-70, 73, 74, 77, 80, 82]. Additionally, four studies focused on knowledge and behaviour [63, 66, 71, 78], three on dietary intake [49, 63, 66], three on smoking abstinence [47, 49, 56], and five on body composition [49, 62, 63, 70, 81].

Table 2: Characteristics of the included studies (n=39)

Categories	Variables, number of studies, references
Type of intervention	Safety and health n=1 [78]
	Organizational 1 [52]
	Behavior 27 [45, 46, 48, 50, 51, 53-55, 57-62, 65, 67-70, 73-76, 81-84]
	Multi-component 10 [47, 49, 56, 63, 64, 66, 71, 77, 79, 80]
Continent	North America 5 [47, 49, 59, 60, 78]
	South America 4 [52, 53, 65, 70]
	Europe 17 [46, 48, 51, 54-56, 62, 68, 69, 71, 73-75, 77, 81-83]
	Asia 12 [45, 50, 57, 58, 61, 64, 66, 67, 76, 79, 80, 84]
	Australia 1 [63]
Intervention duration	Acute interventions (< 6 weeks) 6 [45, 47, 50, 71, 76, 78]
	Sub-acute interventions (6 – 11 weeks) 11 [46, 51, 57, 58, 64, 66, 67, 73-75, 84]
	Mid-term interventions (3 – 6 months) 15 [48, 49, 53-55, 60-63, 65, 68, 70, 77, 81, 82]
	Long-term interventions (>6 months) 7 [52, 56, 59, 69, 79, 80, 83]
Health related outcomes	Physical domain 19 [48, 49, 51, 55-57, 60, 62, 63, 67-70, 73, 74, 77, 81, 82, 84]
	Mental domain 10 [46, 48, 50, 52, 56, 58, 61, 67, 70, 76]
	Social domain 3 [46, 58, 74]
	Knowledge and behavior 4 [63, 66, 71, 78]
	Physiological parameter 6 [50, 62, 63, 70, 76, 81]
	Musculoskeletal disorders 19 [45, 48, 51-53, 57, 60, 62, 64, 65, 67-70, 73, 74, 77, 80, 82]
	Dietary intake 3 [49, 63, 66]
	Smoking abstinence 3 [47, 49, 56]
	Body composition 5 [49, 62, 63, 70, 81]
Measurement of outcomes	Objective measurement 6 [54, 71, 74, 79, 81, 84]
	Subjective measurement 19 [45-47, 49, 53, 56, 58, 60, 61, 64-67, 75-78, 80, 83]
	Both objective & subjective measurement 14 [48, 50-52, 55, 57, 59, 62, 63, 68-70, 73, 82]
Other outcomes	Work-related outcomes 17 [48, 52, 54-57, 59, 61, 70, 75, 77-79, 81-84]
	Other stated 3 [47, 49, 56]

Risk of bias and study quality assessment

The results of the risk of bias assessment for the RCTs are illustrated in Figure 2-5. No studies were excluded based on their risk of bias. All relevant studies were included to provide a comprehensive overview, with quality assessment conducted to inform the analysis. Most studies (n=22) have a high overall risk of bias [45, 50, 51, 53, 55, 58-64, 66-69, 77-80, 82, 83]. The main reasons for this judgment include a high risk of bias in deviations from the planned intervention, inadequate outcome data, and difficulty in measuring outcomes. The high overall risk of bias in eight studies arose from the domain measurement of the outcome [50, 55, 63, 66-68, 82, 83]. Awareness of the outcome assessors and the possible influence was considered as a high potential source of bias. The remaining articles are being judged as some overall concerns [46, 54, 57, 65, 71-76, 81]. The reasons are high risk for insufficient report deviation from predesigned intervention or missing outcome data or a lack of a pre-specified protocol, which raised concerns about selection bias. No study was judged to have a low overall risk of bias.

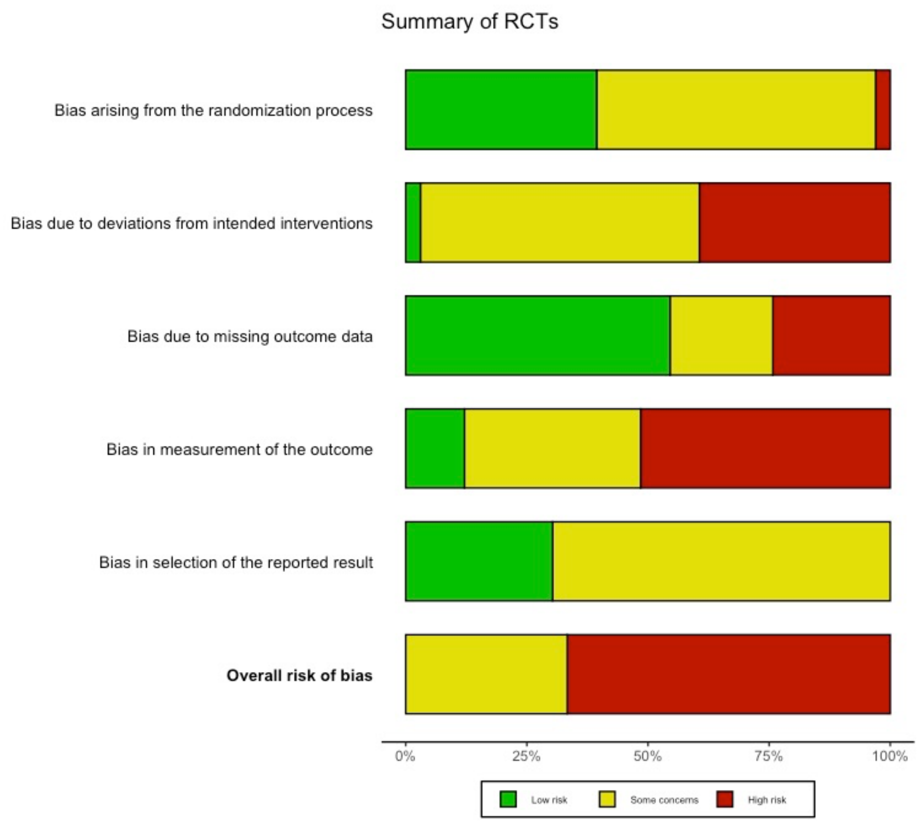

Figure 2: Summary of RoB 2.0 assessment for RCTs

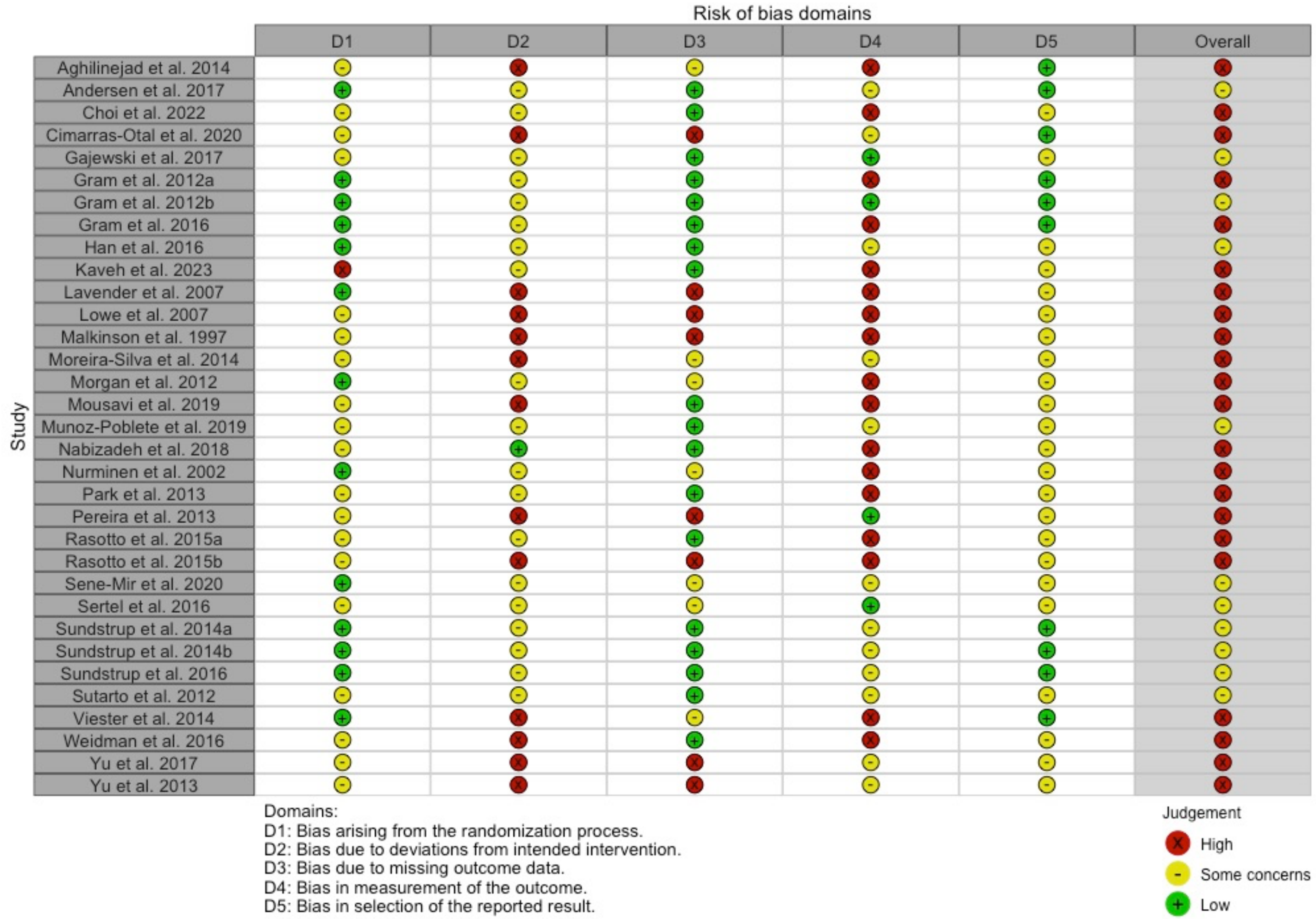

Figure 3: Traffic light plot for RCTs

For the cluster-RCT, four studies were judged as high risk of bias [47, 49, 52, 56], mainly because of a high risk for missing outcome data. One study was judged with a high risk of bias due to the domain deviations from the intended interventions [47]. The other two studies were judged with some concerns [48, 70]. No study was judged to have a low risk of bias.

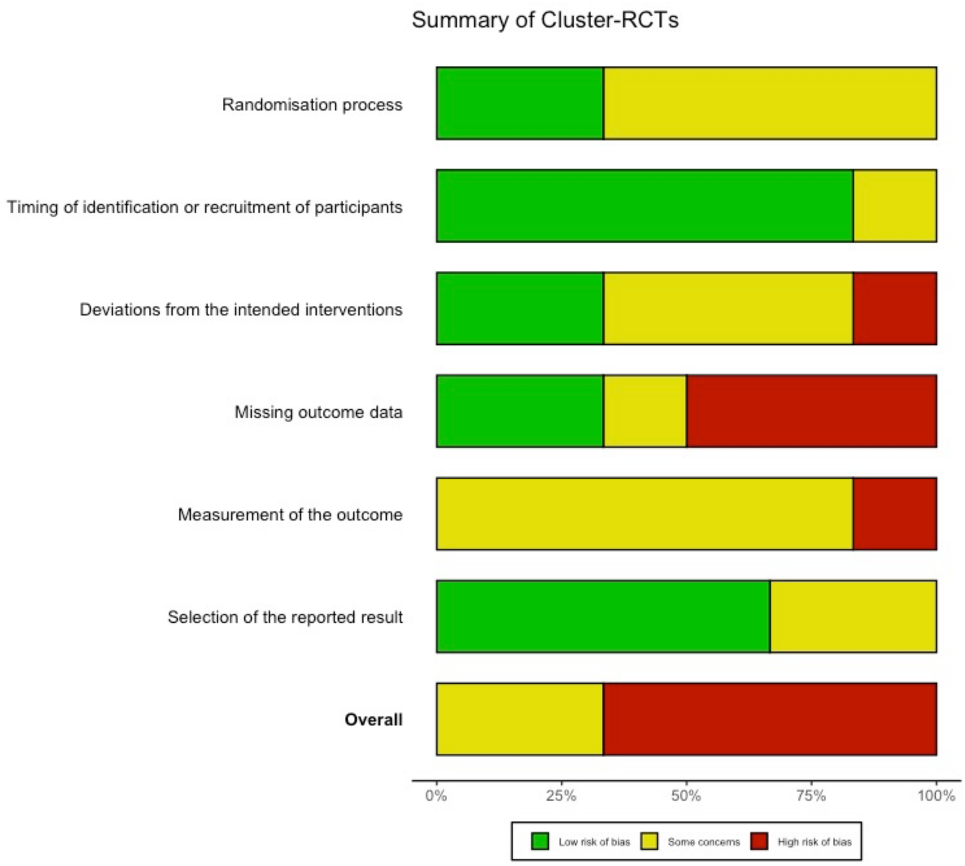

Figure 4: Summary of RoB 2.0 assessment for clusterRCTs

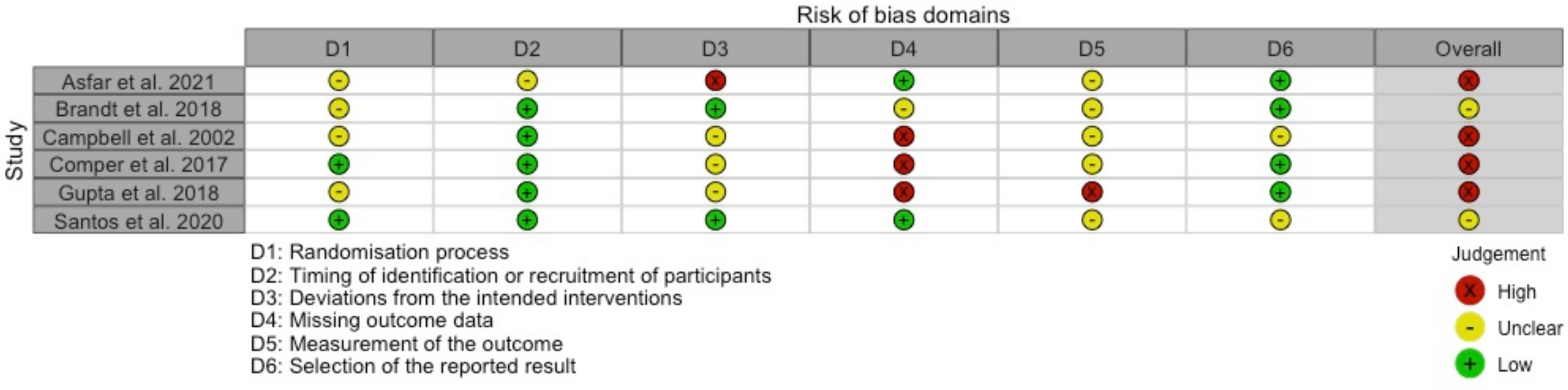

Figure 5: Traffic light plot for clusterRCTs

The methodological study quality assessments are presented in the Tables 3-6. The mean quality score for all the studies was high (71%), ranging from 39% [78] to 93% [73-75]. The corresponding scores were high for the categories' behaviour (71%), organisational (91%) and multicomponent (71%), while safety was moderate (39%). Question 6 received a positive "yes" score across all studies. Similarly, Question 16 received a "yes" score except for the behaviour category.

Behavioural (including exercise) approaches

A total of 27 studies adopting behavioural approaches in workplace health promotion programs for industrial workers were identified (Table 3). The studies included a variety of interventions, such as educational sessions, exercise programs, ergonomic initiatives, and biofeedback training.

Very short-term interventions (<6 weeks, n=3)

Three studies with a behavioural approach used very short-term interventions. One educational study discovered that providing a lecture about low back pain and ergonomic aspects in workers from an automobile factory was beneficial in reducing the incidence of musculoskeletal disorders when compared to the control group [45]. Another study compared a three-day forest therapy to a control group and found beneficial effects on heart rate variability, stress, and mood states. Additionally, improvements in depression treatment, health-related quality of life, and cortisol levels were reported in the intervention group [50]. A study with biofeedback training was more beneficial for heart rate variability, stress, depression, and anxiety than the control group [76].

Short-term interventions (6 – 11 weeks, n=9)

Nine studies have utilised short interventions. In one study educational sessions about stress management were beneficial on stress, spiritual well-being, perceived stress-coping mechanisms, and social support compared to a wait-list control group [58]. The other eight studies compared exercise programs. One study used an elastic band training on healthy female workers, which resulted in improved handgrip strength but no change in VO2 max and on hand skills as a work-related outcome compared to a control group [72]. Seven studies focused on industrial workers with acute or chronic low back pain and compared various exercise programs such as group resistance training [46, 73-75], work-adapted exercises [51], a hamstring stretch program [57], and lumbar stabilisation and Nintendo Wii exercise program [67] to control groups with recommendations [51], personalised ergonomic training [46, 73-75], a generalised treatment [67], and a handout and home training [57]. Mixed effects on physical parameters were reported (improvements in leg raise and sit and reach test strength [57]; increased handgrip strength [74]; shoulder and wrist strength [73]), improved time to fatigue for handgrip [74] and flexibility [51] but not on isometric strength or balance ability [67]). Additionally, mixed effects have been reported regarding mental health (from the SF-36) with beneficial [67] and no effects [46]. However, improvements were found in self-related health [74], social climate and vitality [46], pain intensity [57, 67, 73, 74], pain interference [51], workability [57, 75], and disability [73].

Mid-term interventions (3 – 6 months, n=12)

Two of twelve studies used an educational approach in healthy industrial workers. A stress management program led to beneficial changes in burnout, listlessness, cognitive weariness and work-home conflict as work-related outcomes but not in tension against a control group [61]. Ergonomic initiatives have led to beneficial effects for heavy lifting and fatigue after a typical workday and an increased desire to influence their work but not on pain compared to a control group, who got recommendations [48]. Also cognitive training induced improvements in reaction times, error rates, and event-related potentials compared to a control group [54]. Moreover, a shoulder exercise program benefited shoulder functionality but did not improve musculoskeletal symptoms on assembly line workers [60], whereas an upper-body resistance training program with elastic bands decreased pain intensity [65]. A tailored mobilisation program improved range of motion, handgrip strength, pain intensity, and disability [68]. Stretching exercises lead to beneficial effects on pain intensity [53, 62], while no effects were observed on self-reported physical activity, blood pressure, waist circumference, or body fat [62]. A tailored aerobic and strength training program on construction workers [55, 81, 82] increased VO2max [81] but did not change other parameters compared to a control group with educational sessions (isometric strength [81], perceived physical exertion [82], blood pressure, lipid parameters, BMI [81], pain intensity, workability, productivity, sick leave [82]). Furthermore, after this treatment, a decrease in objectively measured physical activity during weekdays and leisure time was reported compared to the control group [55]. In a study with progressive resistance training no effects were observed on any outcome (maximum muscle strength, self-reported physical activity, perceived fatigue, blood pressure, musculoskeletal complaints, body fat, BMI, perceived risk factors, or productivity) compared to a control group who performed general exercise using elastic bands [70].

Long-term interventions (>6 months, n=3)

A long-term intervention using strengthening, endurance, and stretching exercises on female industrial workers did not lead to beneficial effects on job satisfaction, workability, or sick leave compared to controls which received recommendations and feedback [83]. A tailored mobilisation and strengthening program on manufacturing workers improved range of motion, handgrip strength, pain intensity, and disability [69], whereas a biofeedback training study found no beneficial effects on injury rates compared to a control group [59].

Table 3: Characteristics and synthesis of the studies with behavioral approach using PICO scheme and quality assessment

Study	Sample size (n)	Population	Intervention	Control	Outcome	Score (%)	Quality
Aghilinejad et al. 2014 [45]	503	Factory workers who did not have an extra job within free time, history of fracture or major trauma, degenerative disk disease, spondylosis, spinal stenosis, neurological deficit and systemic illness or are on vacation (intervention 31 ± 5 years; control 30 ± 2 years).	First education group got lecture on LBP and related ergonomic aspects. Second education group were given a pamphlet which contained schematic diagrams reflecting the topics LBP and related ergonomy as presented orally to the first group. Third education group had a workshop discussing several aspects of LBP and ergonomics.	No intervention.	prevalence of low back pain	61	moderate

Andersen et al. 2017 [46]	66	Mainly male slaughterhouse workers working at least 30 hours per week, have upper limb musculoskeletal pain of at least 3 on a scale of 0 to 10, some work disability, not having participated in either strength training or ergonomics instruction during last year (on average 45 ± 10 years).	Group-based physical exercise consisting of eight different exercises. Sessions were supervised. Load and resistance were increased according to the principle of progressive overload: Repetitions decreased over time from a maximum 20 to 8 as a standard for each exercise and load increased.	Individual ergonomic training and education based on workplace analysis and hazard prevention system.	Social climate; SF-36 (Mental health and Vitality)	82	high
Brandt et al. 2018 [48]	80	Male construction workers (intervention 34.2 ± 12.5 years; control incomplete data).	Participants received 3 workshops due to reflection of the working progress in 3 phases to improve physical exertion.	Handouts about WMSD and lifting guidelines.	Physical workload; fatigue after a typical workday; desire to influence the work; pain intensity	88	high

Choi et al. 2022 [50]	42	Male manufacturing workers who were full-time employees from a public sector, being adult (18 to 65 years) and were in active employment in manufacturing industry. Exclusion criteria were concurrent psychiatric illnesses, being a frequent user of natural environments (visiting more than 3 times a week), taking medications including hypertensive, diabetes or pain relievers (including oral hormone/corticosteroid drugs) and history of outdoor allergens in which allergic disease can exacerbate of psychological stress and discomfort (intervention 43.5 ± 7.3 years; control 45.9 ± 8.2 years).	Forest therapy.	No intervention.	Heart rate variability; stress; mood states; depression treatment, health related quality of life; cortisol level	68	high

Cimarras-Otal et al. 2020 [51]	40	Mainly male assembly line workers with chronic low back pain for at least the previous 3 month, not incapacitated in terms of job performance and owned a smartphone. Were excluded with lumbar lesion that did not allow to perform at work or undertake a physical exercise program and incompatible smartphone (on average 42.2 ± 6.2 years).	Tailored compensatory exercise, strengthen inactive muscle groups, stretching active muscles, mobilize lumbar spine and increase cardiovascular exercise. Additionally general exercise recommendations based on ACSMs approach.	General exercise recommendations based on ACSMs approach.	Lumbar disability; pain intensity; angle, bending speed; flexion-extension ratio	75	high
Gajewski et al. 2017 [54]	60	Male healthy industrial workers (on average 46.5 ± 4.5 years).	Reception of trainer-guided cognitive training (formal paper- and computer-based).	Delayed intervention but mixed with stress management and relaxation training (REL) in the first eight sessions and in the remaining 12 sessions same as intervention group.	Reaction times; Error rates; event-related potentials	50	moderate

Gram et al. 2012 [81]	67	Male construction workers with physical demanding work in including high peak demands and work for more than 20 hours per week (on average 43.7 ± 10.5 years).	Participants received supervised and individually tailored aerobic capacity training and muscle strength training.	Presentation about general health promotion and usual care.	Isometric strength of different body parts; systolic and diastolic blood pressure; HDL and LDL-cholesterine; triglycerides; body weight; BMI; body fat percentage; maximal oxygen consumption;	89	high
Gram et al. 2012 [82]	102	Male construction workers with physical demanding work in including high peak demands and work for more than 20 hours per week (on average 43.7 ± 10.5 years).	Participants received supervised and individually tailored aerobic capacity training and muscle strength training.	Presentation about general health promotion and usual care.	Pain intensity of different body parts; work ability; perceived physical exertion at work; productivity; sick leave	89	high
Gram et al. 2016 [55]	67	Male construction workers with physical demanding work in including high peak demands and work for more than 20 hours per week (on average 43.7 ± 10.5 years).	Participants received supervised and individually tailored aerobic capacity training and muscle strength training.	Presentation about general health promotion and usual care.	Physical activity; Energy expenditure due to physical activity; Intensity of physical activity	79	high

Han et al. 2016 [57]	100	Assembly line workers with low back pain, working at least 8 hours per day in a standing position and had less than 80° of the Straight leg raise (SLR) test. Participants were excluded at history of fracture and surgery, with disc herniation, acute low back pain, systemic diseases, osteoarthritis, spondylolisthesis and spondylolysis, leg length discrepancy, pregnancy and any low back pain with known causes (intervention groups 38.1 ± 6.5 and 39.7 ± 7.6 years, respectively; control 37.8 ± 8.7 years).	First intervention group have done pelvic control hamstring stretching and lumbopelvic muscle strengthening. Second group received general hamstring stretching.	Participants were told to do home program and received the handout with lumbopelvic muscle strengthening and hamstring stretching methods.	leg raise test; sit and reach test; pain intensity; workability	68	high

Kaveh et al. 2023 [58]	106	Mainly male industrial workers with more than one year of job tenure, no history of stress management education nor psychiatric treatment. Were excluded when absent from two educational sessions, not attending the pre-test or post-test sessions, withdrawal from the study or undergoing treatment by a psychiatrist due to mental illness during the intervention (intervention 35.8 ± 5.2 years; control 36.2 ± 5.9 years).	A transactional model-based education programme delivered to participants to enhance stress-coping skills. Methods were lecture, question/answer, group discussion and role play.	No intervention.	stress; spiritual well-being; perceived stress coping mechanism; social support	68	high
Lavender et al. 2007 [59]	1977	Workers with required repetitive lifting (on average 33.5 years).	Participants received the LiftTrainer™ program that was conducted by a coach using a 1-on-1 format that allowed the training to be individualized for each employee.	Video-training program.	Injury rates	46	moderate

Lowe et al. 2017 [60]	76	Assembly workers with work that have overhead processes in common (intervention 33.3 ± 8.6 years; control 37.4 ± 10.3 years).	Participants received an exercise program included resistance band strengthening movements and stretching/lengthening of the pectoralis and trapezius muscles. Progressive overload was given. Participants were encouraged to attend as many sessions per week as possible.	No intervention.	Shoulder functionality; discomfort of the shoulder; musculoskeletal symptoms	46	moderate
Malkinson et al. 1997 [61]	27	Female production workers with little formal education, based on the cognitive approach of Rational-Emotive-Behavioral Training (on average 35.3 years).	Participants received rational-emotive behavior therapy.	No intervention.	Burnout; tension; listlessness; cognitive weariness; work-home conflict	46	moderate
Moreira-Silva et al. 2014 [62]	74	Factory workers (on average 38.4 ± 7.4 years).	Participants received physical exercise focused on stretching of different body regions. Additionally, they participated in strength exercises for lower extremities. Participants were given a program to workout at home. They were asked to start recreational aerobic activities in every session.	Usual care.	Musculoskeletal pain intensity; physical activity; blood pressure; body fat; waist circumference	57	moderate

Muñoz-Poblete et al. 2019 [65]	109	Manufacturing workers with a maximum age of 40 years and asymptomatic or light musculoskeletal issues of the upper extremities with low intensity (VAS ≤ 30mm; OCRA-Score ≥ 7.5). They were excluded with a work history lesser than one year, history of musculoskeletal trauma of the upper extremities and cardiovascular or other systemic diseases (on average 28.7 ± 5.4 years).	Participants received training sessions aiming a progressive strength training with resistance bands. In phase one shoulder stabilized muscles were focused. At least forearm muscles, shoulder rotation and elevation were added in phase 2 and 3.	Daily routine of established stretching exercises should go on. One by a physiotherapist lessoned worker supervised those exercises.	Pain intensity of different body regions	63	moderate
Nurminen et al. 2002 [83]	260	Female laundry workers with physically demanding work who were permanently employed and without contraindications for physical capacity tests (intervention 40.7 years; control 39.1 years).	Participants received feedback on their physical capacity from a physiotherapist, individual exercise prescription, counseling and worksite exercise training which involved strength training, cardiovascular exercise and stretching with progressively intensity increasing..	Participants received feedback on their physical capacity from a physiotherapist, individual exercise prescription and counseling.	Job satisfaction; workability; sick leave	68	high

Park et al. 2013 [67]	24	Factory workers diagnosed with low back pain for at least 3 months, not experienced operative interventions related to spina bifida, prolapse or spinal canal stenosis (on average 44.3 ± 5.2 years).	First intervention group received stabilization exercise for the lumbar spine, additionally to physiotherapeutic treatment. Second group have done exercises with game console Nintendo Wii.	Physiotherapeutic treatment.	Pain intensity; isometric strength; Balance ability; RAND-36 physical and mental score	54	moderate
Pereira et al. 2013 [53]	61	Garment workers who have worked in the sewing and finishing sectors of the clothing factory, have done this type of work for at least 1 year, are willing to participate in the research by signing a consent form and have never participated in a physical activity program at the workplace before. Excluded with clinical manifestations which were incompatible with the programme offered, such as a physical or mental disability and/or any pre-existing disorder that could be aggravated by participating in a physical activity program at the workplace (intervention 28.7 ± 8.8 years; control 27.8 ± 7.4 years).	Physical activity programs consisting of stretching exercises (40%), muscular endurance (40%), self-massage relaxation and massage techniques (10%) and group dynamics (10%).	No intervention.	Pain intensity	57	moderate

Rasotto et al. 2015 [69]	68	Male assembly workers at least 18 years or older who had no training specific contraindications. Excluded when participated at a structured exercise program for physical activity in the last 6 month, had diseases of the central nervous system like hemiparese, myelopathy, cerebral ataxy and muscular deformities like amputation or scoliosis and abnormalities like arthritis, that limitated movement through pain, a history of cardiovascular disease which made exercise impossible like angina or position dependable hypotonus (on average 41.1 ± 7.7 years).	Participants received tailored exercise training sessions. The first month for familization. Complaint specific exercises have been chosen. With pain mainly mobilization exercise, without pain strength exercises with light dumbbells or resistance bands carried out.	Individual daily activity has been maintained.	Pain intensity; shoulder elevation; shoulder abduction; head flexion; head extension; head rotation; head lateral inclination; handgrip strength; disability	86	high

Rasotto et al. 2015 [68]	60	Female assembly workers who had no training specific contraindications. Excluded when participated at a structured exercise program for physical activity in the last 6 month, had diseases of the central nervous system like hemiparese, myelopathy, cerebral ataxy and muscular deformities like amputation or scoliosis and abnormalities like arthritis, that limitated movement through pain, a history of cardiovascular disease which made exercise impossible like angina or position dependable hypotonus (on average 39.2 ± 6.2 years).	Participants received tailored exercise training sessions. The first month for familization. Complaint specific exercises have been chosen. With pain mainly mobilization exercise, without pain strength exercises with light dumbbells or resistance bands carried out.	No intervention.	Pain intensity; shoulder elevation; shoulder abduction; head flexion; head extension; head rotation; head lateral inclination; handgrip strength; disability	86	high
Santos et al. 2020 [70]	204	Mainly male industrial workers allocated in production sectors aged 18 to 65 years. Were excluded if they got outsourced or temporary restrictions from the medical department (intervention 34.3 ± 11.9 years; control 37.7 ± 12.9 years).	Participants received resistance exercises using progressively greater loads.	General exercise using elastic bands.	Maximum muscle strength; physical activity; fatigue; blood pressure; musculoskeletal disorders; body fat; BMI; perceived risk factors; productivity	86	high

Sertel et al. 2016 [84]	91	Female industrial workers without any disease or condition known to affect the physical performance, a history of an occupational accident and/or disease and any other injuries and conditions resulting in limited range of motion, had no reduced strength and endurance, and deformity in any of the upper extremity joints, not experienced pain and/or musculoskeletal problems or demonstrating unwillingness during the assessments and exercise programs (on average 33 ± 5.4 years).	First intervention group have done elastic bands strengthening. Second group received endurance training with repetitive movements.	No intervention.	Maximal oxygen consumption; Hand skills; handgrip strength	68	high

Sundstrup et al. 2014 [75]	66	Mainly male slaughterhouse workers currently working for at least 30 hours a week, had pain intensity in the shoulder, elbow/forearm, or hand/wrist of 3 or more on a 0 to 10 visual analog scale (VAS) during the last 3 months, stated at least some work disability scoring on a 5-point scale, had no participation in resistance training during the last year or no ergonomic instruction during the last year. They were excluded with hypertension, a medical history of cardiovascular diseases, recent traumatic injury of the neck, shoulder, arm, or hand regions and pregnancy (intervention 48 ± 9 years; control 43 ± 9 years).	Participants received resistance training.	Ergonomic training (usual care).	Workability	93	high

Sundstrup et al. 2014 [73]	66	Mainly male slaughterhouse workers currently working for at least 30 hours a week, had pain intensity in the shoulder, elbow/forearm, or hand/wrist of 3 or more on a 0 to 10 visual analog scale (VAS) during the last 3 months, stated at least some work disability scoring on a 5-point scale, had no participation in resistance training during the last year or no ergonomic instruction during the last year. They were excluded with hypertension, a medical history of cardiovascular diseases, recent traumatic injury of the neck, shoulder, arm, or hand regions and pregnancy (intervention 48 ± 9 years; control 43 ± 9 years).	Participants received resistance training.	Ergonomic training (usual care).	Pain intensity; disability; Shoulder rotation strength; Wrist extensor strength	93	high

Sundstrup et al. 2016 [74]	66	Mainly male slaughterhouse workers currently working for at least 30 hours a week, had pain intensity in the shoulder, elbow/forearm, or hand/wrist of 3 or more on a 0 to 10 visual analog scale (VAS) during the last 3 months, stated at least some work disability scoring on a 5-point scale, had no participation in resistance training during the last year or no ergonomic instruction during the last year. They were excluded with hypertension, a medical history of cardiovascular diseases, recent traumatic injury of the neck, shoulder, arm, or hand regions and pregnancy (intervention 48 ± 9 years; control 43 ± 9 years).	Participants received resistance training.	Ergonomic training (usual care).	Handgrip strength; Fatigue for handgrip; self-related health; Pain intensity	93	high
Sutarto et al. 2012 [76]	27	Female healthy manufacturing workers with little formal education, based on the cognitive approach of Rational-Emotive-Behavioral Training (on average 35.3 years).	Participants received rational-emotive behavior therapy with biofeedback training of HRV.	No intervention.	heart rate variability; stress; depression; anxiety	50	moderate

Organisational interventions

Only one study implemented ergonomic training followed by a 12-month job rotation at the organisational level (Table 4). However, no improvements were found compared to a control group that received ergonomic training (need for recovery, quality of life, musculoskeletal disorders, prevalence of pain, sick leave, productivity) [52].

Table 4: Characteristics and synthesis of the studies with organisational approach using PICO scheme and quality assessment

Study	Sample size (n)	Population	Intervention	Control	Outcome	Score (%)	Quality
Comper et al. 2017 [52]	266	Mainly female manufacturing workers arranged in a manufacturing cellular and serial layout with jobs or tasks with different biomechanical demands and levels of risk for musculoskeletal disorders (intervention 28.4 ± 7.8 years; control 32.5 ± 9.0 years).	Ergonomic training and additional job rotation were performed.	Only ergonomic training.	Need for recovery; quality of life; musculoskeletal disorders; prevalence of pain; sick leave; productivity	91	high

Multicomponent approaches

Ten studies have implemented a multicomponent approach of different durations [47, 49, 56, 63, 64, 66, 71, 77, 79, 80] (Table 5). These studies combined interventions such as educational training, behavioural approaches, exercise programs, and nutritional education.

Very short-term interventions (<6 weeks, n=2)

Two studies included educational training with the addition of behavioural approaches. A multi-component program on quitting smoking from construction workers had no beneficial effect on smoking abstinence but got high feasibility and an acceptable rate against a control group with recommendations [47], whereas a self-observation and feedback program on blue-collar workers compared to a control group with general treatment was beneficial on knowledge of working postures [71].

Short-term interventions (6-11 weeks, n=2)

Two studies on factory workers used custom insoles and lower limb exercise training in a three-group randomised control design showed beneficial effects on musculoskeletal disorders in favour of the group that received both training and insoles [64]. A nutrition education program benefited workers' motivation, knowledge, intention, and consumption of specific vitamins more than a control group who received educational pamphlets [66].

Mid-term interventions (3-6 months, n=3)

A program focusing on weight loss was beneficial for physical activity and physical activity-related cognition, physiological parameters (resting heart rate, blood pressure), body compositions (BMI, weight loss, and waist circumference), and some parts of dietary intake (increased consumption of fruits and sweetened beverages, but non-beneficial on vegetable and alcohol consumption) compared to a wait-list control group [63]. A tailored program on female workers increased consumption of fruits and vegetables but led not to smoking abstinence, lower BMI, and cancer screening. Additionally, improvements in flexibility and dietary fat scores were reported to be beneficial after six months but not after a follow-up of 18 months. An increase in physical activity in the intervention group was reported, but the difference was not statistically significant compared to control group with educational sessions [49]. One intervention program on construction workers focusing on preventing and reducing overweight and musculoskeletal symptoms was non-beneficial on physical functioning, musculoskeletal disorders, workability, sickness absence, work-related vitality and performance against a control group [77].

Long-term interventions (>6 months, n=3)

In manufacturing workers educational sessions, strength and stretching training, and games reduces work-related injuries [79] and musculoskeletal disorders in specific body parts compared to a control group with educational sessions [80]. In contrast, different workshops have no beneficial effects in industrial workers compared to a control group (leisure-time physical activity, physical resources, need for recovery, well-being, mental health, smoking abstinence, workability, physical work demands, productivity, or employees' appraisal of intervention activities) [56].

Table 5: Characteristics and synthesis of the multicomponent-studies using PICO scheme and quality assessment

Study	Sample size (n)	Population	Intervention	Control	Outcome	Score (%)	Quality
Asfar et al. 2020 [47]	134	Male construction workers ≥ 18 years old who were hispanic or latino, smoking ≥ 5 cigarettes per day for the past year, were interested in making a quit attempt in the next 30 days, having access to a telephone and not planning to move in the next 6 months. They were excluded if having a contraindication to nicotine replacement treatment (NRT; e.g. recent myocardial infarction, history of serious arrhytmias) or inability to understand consent procedures (intervention 40.9 ± 1.5 years; control 38.2 ± 1.4 years).	Based on social cognitive theory participants received one culturally adapted face-to-face counseling session, followed by two brief phone calls, 6 weeks of NRT, fax referral to Florida quit line (four brief phone conseling sessions; two weeks of free NRT), informative handouts about the Florida quit line and benefits of quitting smoking.	Only 6 weeks of NRT, fax referral to Florida quit line (four brief phone conseling sessions; two weeks of free NRT) and informative handouts about the Florida quit line.	smoking abstinence; feasibility and acceptance of the intervention	73	high

Campbell et al. 2002 [49]	649	Female blue-collar workers over 18 years old, speaking English or Spanish from small to medium-size blue collar industry which employing a majority of women. It had no systematic health promotion program currently in place and no plans for immediate plant closure. Excluded were factories where not enough women or too many employees were shown, the plant closed or about to close, already had a comprehensive health promotion program, was not the right industry or county, had no permanent employees, had a wrong address or duplicate listing and did not have authority at the worksite to agree to a program (no mean age reported).	Individualized computer-tailored “women’s magazines”; a natural helpers intervention that trained women in the workplace to diffuse information and a health education to support healthy behavior changes.	Delayed intervention worksites were offered a menu of possible health education sessions for their employees on topics not directly related to study objectives; after 6 month same tailored magazines as intervention but no natural helpers program.	Consumption of fruits and vegetables; smoking abstinence; BMI, cancer screening; flexibility; fat score; physical activity	43	moderate

Gupta et al. 2018 [56]	415	Manufacturing workers from workplaces with a minimum of 100 workers and team-based physical work with cooperative relations between hierarchy levels. Teams required formal work groups and individuals had to have upon 20 h work time per week and study consent (on average 44.1 ± 10.5 years).	Workshops were conducted at different levels of the organization to enhance productivity, wellbeing, and health and safety. At the group level, participants attended three workshops. The first workshop focused on visual mapping, teaching participants to identify factors that positively or negatively affect workability, such as demands and resources. The second workshop centered on action planning, where participants translated their learnings into concrete plans displayed on whiteboards. The effectiveness of these plans in supporting productivity, wellbeing, product quality, and cost effectiveness was evaluated. The third workshop provided an opportunity for workers and supervisors to exchange ideas and offered additional options	No intervention.	Need for recovery; Workability; Productivity; Physical work demands; Physical resources; leisure-time physical activity; Well-being; Mental health; smoking abstinence	89	high

			like individual visual mapping talks and ergonomic workshops. At the leadership level, ambassador workshops were held to disseminate knowledge on promoting health and safety among workers. These workshops aimed to foster a culture of well-being and safety throughout the organization.				
Morgan et al. 2012 [63]	110	Male industrial shift workers who were overweight or obese (BMI between 25 and 40 kg/m^2), aged 18–65. Excluded at history of major medical problems such as heart disease in the last 5 years, diabetes, orthopaedic or joint problems that would be a barrier to physical activity, recent weight loss of ≥ 4.5 kg or taking medications that might affect body weight (on average 44.4 ± 8.6 years).	Behaviour change strategies consisting of information session, handbook, study website, website tutorial and user guide. 7 individualized dietary feedback sheets and group-based financial incentive pedometer were given.	No intervention.	Body weight; waist circumference; BMI; blood pressure; resting heart rate; Physical activity; Dietary; Physical activity cognitions; Healthy eating practices; Dietary state of change (SOC)	75	high

Mousavi et al. 2019 [64]	100	Male production line workers with at least 1 year of work experience and standing for at least 3 hours per day at work. Participants were excluded with any reports of lower limb or back injury such as fracture, dislocation, soft tissue lesions (during the previous 6 months), any history of surgery in the muscles, joints, or bones in the lower back and lower extremities, musculoskeletal diseases and neuromuscular disorders such as joint rheumatism, myopathy or neuropathy, foot deformity including raised or flattened arches or hallux valgus, and any vascular problems in the lower extremities (on average 35.9 years).	First group got custom-made insoles and lower limb exercises. Second intervention group had insoles only, and third group had lower limb exercises only.	No intervention.	Musculoskeletal disorders; discomfort level in back, thigh, knee, leg and foot.	71	high

Nabizadeh et al. 2018 [66]	210	Male cement factory workers who did not present a history of, or current, physical symptoms of serious neurological, cardiovascular, renal, hepatic, endocrine, metabolic or gastrointestinal disease and previous pharmacological treatment, according to the medical reports available at the factory (intervention groups 34.6 ± 4.5 and 33.8 ± 4.9 years, respectively; control 34.7 ± 4.8 years).	Participants received educational interventions based on the Protection Motivation Theory (PMT). Face-to-face group had multimodal lectures with powerpoint presentations, discussion, questions and answers, individual counselling sessions and educational pamphlets and booklets. Indirect group received recently designed educational content through pamphlets and booklets.	No intervention.	Motivation; knowledge; intention; consumption of Vitamin C and E	64	moderate
Sene-Mir et al. 2020 [71]	61	Mainly female blue-collar workers ≥ 18 years old who not suffer any chronic bone, muscle, or joint disease in the trunk, and/or chronic or acute pain diagnosed by a specialist. Not suffer, any chronic or acute knee joint disease diagnosed by a specialist (no age described).	Received intervention which contained systematic self-observation, hetero-observational, feedback as well as feedforward and intrinsic feedback.	Standard manual material handling training.	Knowledge of working postures	68	high

Viester et al. 2014 [77]	314	Construction and production workers without sick leave within last 4 weeks before intervention (on average 46.6 ± 9.7 years).	Participants received training to improve lifestyle including individual information, personal or phone contacts, exercises and material tailored to body weight, physical activity and motivation of lifestyle change. They got a periodic review of knowledge about healthy lifestyle and will to change.	Maintainance of daily activities.	Physical functioning; musculoskeletal disorders; workability; sick leave; work-related vitality; performance	86	high
Yu et al. 2013 [80]	3479	Mainly male manufacturing workers employed at medium-size industrial companies (with employees from 300 to 2,000) that should be matched with another factory by industry and production processes, with a less than 30 % turn-over rate of workers in 1 year. Participants: were frontline workers and being employed in the current factory for at least 12 months. They were excluded if employed in administration, design and logistics or are illiterate and seasonal migrant workers (intervention 29.1	Participatory training of learning successful examples from other workplaces. Program includes personal protective equipment usage, stretching and strengthening exercise and games including ergonomic and materials handling.	Didactic training of only a short presentation, without group discussions, games or workplace visits.	Musculoskeletal disorders	75	high

		± 7.3 years; controls 28.9 ± 7.4 and 28.3 ± 7.1 years, respectively).					
Yu et al. 2017 [79]	3479	Mainly male manufacturing workers employed at medium-size industrial companies (with employees from 300 to 2,000) that should be matched with another factory by industry and production processes, with a less than 30 % turn-over rate of workers in 1 year. Participants: were frontline workers and being employed in the current factory for at least 12 months. They were excluded if employed in administration, design and logistics or are illiterate and seasonal migrant workers (intervention 29.1 ± 7.3 years; controls 28.9 ± 7.4 and 28.3 ± 7.1 years, respectively).	Participatory training of learning successful examples from other workplaces. Program includes personal protective equipment usage, stretching and strengthening exercise and games including ergonomic and materials handling.	Didactic training of only a short presentation, without group discussions, games or workplace visits.	Incident rates of accidental injury	68	high

Safety interventions

One intervention study on drywall-finishing workers was conducted to improve safety outcomes through education. Positive effects were found on self-efficacy and trust in technology, but not in health knowledge, perceived health risk, and trust in the organization when compared to the control group (Table 6). For the parameter readiness to adopt the tool, beneficial effects were reported at the end of the intervention but not at the follow-up [78].

Table 6: Characteristics and synthesis of the safety interventions studies using PICO scheme an quality assessement

Study	Sample size (n)	Population	Intervention	Control	Outcome	Score (%)	Quality
Weidmann et al. 2016 [78]	40	Male drywall-finishing workers.	Didactic and interactive training, information about dust material composition, health effects of dust exposure, usefulness of ventilated sanders. Cues to action wearing hard-hat stickers and t-shirts. Improving worker self-efficacy and trust in technology at trying and testing the new technology.	No intervention.	Health knowledge; self-efficacy; Perceived risk to health; trust in Technology; trust in organization; adoption readiness.	39	moderate

Discussion

In total 39 RCTs were included in this systematic review on the effectiveness of workplace-related health interventions in industrial workers. The majority of studies (n=27) adopted behavioural interventions. Among them, most studies used exercise programs, followed by educational approaches. Ten studies employed multicomponent interventions with combinations of educational interventions and behavioural or organisational approaches, one opted for an organisational approach, and one study focused on safety-related outcomes. In most studies, there was a high overall risk of bias, necessitating a cautious interpretation of all results.

Intervention characteristics

Most behavioural studies used an exercise program, while others employed an educational approach. Exercising seems to be a promising tool for health-related outcomes in musculoskeletal [29, 30, 85] and cardiometabolic disorders [31] as well as on mental health outcomes [3, 86]. Educational programs might have a positive impact on mental health [30, 87], but other health-related outcomes, such as musculoskeletal disorders, might not profit [29]. Nevertheless, a positive impact of educational strategies on work-related outcomes, as demonstrated in other contexts with shift workers [88], emphasizes their importance and warrants additional research.

Only one study used an organisational approach in form of job rotation. This is somewhat surprising as recommendations for adding organisational components to improve health-related outcomes were given [89]. The potential advantages of such interventions have yet to be thoroughly explored [9, 43, 90].

In studies on multicomponent approaches, educational programs combined with behavioural or organisational approaches were frequently used. However, inconclusive effects were reported on health-related outcomes in workplace health promotion [29, 91].

A single study was conducted to enhance safety outcomes, underscoring the need for additional research. Health-promoting behaviours might be associated with safety-related outcomes [92].

Effectiveness on health-related outcomes

The findings from the current review revealed several studies demonstrating the effectiveness of workplace intervention in improving specific aspects of health. Mixed effects were found in the studies that examined physical outcomes. Strength outcomes were generally beneficially impacted by workplace interventions. This is consistent with previously reported findings [29, 93]. Conversely, the effects on aerobic capacity varied. Whilst other research found beneficial effects on peak oxygen consumption [94], we found no beneficial effect. An explanation for this discrepancy might be the limited number of studies incorporated in our review. In one study using objectively measured physical activity, a decrease of physical activity was found, contradicting prior research [95-97]. A systematic review and meta-analysis of workplace health promotion programs among men reported nearly half of the included studies showed improvements in physical activity outcomes [98]. The potential differences may be attributed to the fact that physical activity needs to be considered holistically to counteract a possible physical activity paradox and ensure health benefits [99].

In line with other reviews and meta-analyses, our results showed beneficial effects of workplace health promotion on mental outcomes [30, 87, 96, 100]. Regarding physiological parameters, we observed no consistent trends. While other reviews suggested that workplace health promotion affects biological risk factors [95] or enhances cardiometabolic markers [31], our findings did not provide a clear conclusion. However, a systematic review of reviews reported inconsistent findings regarding metabolic risk factors [101].

Furthermore, only a few studies showed beneficial effects on social parameters. Research emphasises the relevance of detecting these outcomes [97, 102, 103].

Regarding parameters related to musculoskeletal disorders, most studies indicated a beneficial effect of workplace interventions, regardless of duration and intervention characteristics. This finding aligns with previous research on workers with physically demanding jobs [1, 29, 30]. One systematic review of longitudinal studies showed the multifactorial etiologic of musculoskeletal disorders and identified psychosocial workplace factors associated with the risk and progression of musculoskeletal disorders [104].

Our findings indicate limited beneficial effects on body composition, as well as in interventions that focus on that topic. This somewhat contrasts beneficial outcomes reported in other research [30, 89, 91, 93, 96, 98]. These disparities may arise from the different populations. Thus, industrial workers' body composition is a significant concern [105], necessitating different interventions and strategies. In contrast, beneficial effects on dietary outcomes were identified, particularly in the context of multicomponent studies. This aligns with prior research and underscores the significance of these findings [30, 95, 96, 106].

Our findings suggest that workplace health promotion initiatives do not significantly impact on smoking cessation rates, which is in line with the systematic review and meta-analysis from Bezzina and colleagues [98]. This contradicts the findings of a meta-analysis on general workers [107]. Nevertheless, the authors concluded that while interventions are effective in stopping smoking, the absolute number of workers who successfully quit is minimal [107], which aligns with our results.

We found heterogeneous results for work-related outcomes. This is possibly a result of the wide range and complex construct to measure work-related outcomes [14]. However, other reviews suggest the potential impact on work-related outcomes through workplace health promotion [9, 14].

Consequently, there is some potential for workplace health interventions but their effectiveness remains unclear. Additionally, it is unclear whether particular types of interventions, such as behaviour or organisational interventions, are more effective than others. Similar to previous systematic reviews on workplace health promotion, it remains challenging to establish firm recommendations about the effectiveness of workplace interventions or identify the types of interventions that demonstrate the most promise [9, 108-111].

Population- and workplace-specific needs

In the industrial sector, sex or gender-specific needs and health hazards have to be considered [27, 112]. Most industrial workers in this review were males, so workplace health promotion interventions might be needed to favour this group. Moreover, a wide variety of industrial tasks [113] with different work paces [114], environments [115], physical demands [116, 117], and shift work [118] can impact health-related factors as possible cofounders. Also, the different health conditions of the participants demonstrate the necessity to focus on their different characteristics. Several studies have focused on industrial workers with at least one health risk. This might be an appropriate representation of industrial workers considering the major concerns related to musculoskeletal disorders [1, 9], metabolic syndrome [119], and mental health [43]. Focusing on the concerns of industrial workers could be an effective approach to developing more targeted and specialised programs [120]. This is particularly important when considering the effectiveness and transferability of interventions in lower-income countries or countries with fewer medical conditions [121]. Additionally, a systematic review reported the factors of economic, management support, intervention concepts, data collection, and resources and commitment to intervention influencing workplace health promotion [122]. Therefore, healthy leadership might be a principle which should be considered [102]. Furthermore, another systematic review reported barriers to workplace health promotion, such as time, a busy lifestyle, and lack of motivation [93]. Addressing needs with tailored activities might lead to a high participation of workplace health promotion programs [28]. Our mixed findings underscore the importance of tailoring interventions based on duration for effective implementation in an occupational health context.

Most of the studies lasted 3-6 months, which may be necessary for behavioural modification. Shorter durations may not be sufficient, as changes depend on the frequency and direction of the modifications that individuals consider [123].

This review has shown that long-term intervention effects were assessed in only a few of the studies. Moreover, many studies have not provided sufficient information regarding the follow-up duration. Only seven of the included studies had a true post-intervention follow-up.

Risk of bias and methodological quality of studies

The high overall risk of bias in this review is consistent with findings from others [13, 31, 106]. The main sources for a high risk of bias resulted from high risks for deviations from the planned intervention, inadequate outcome data assessment, difficulty in measuring outcomes, awareness of the outcome assessor, insufficient report deviation from predesigned intervention, or a lack of a pre-specified protocol. These risks can influence the results of the individual studies in terms of an overestimation or underestimation of the intervention's true effect [124, 125]. Future studies should prioritise the development of well-designed study protocols and enhance the transparency of data. Additionally, data collection should be conducted using valid measurement methods. Further improvements may the blinding of researchers to improve objectivity and rigour in the research process. By addressing these sources of bias, future research can provide more reliable and valid results, ultimately contributing to better evidence-based practices.

As most of the reviewed studies only relied on self-reported outcomes the measurement of health-related outcomes should be considered in future work. Therefore, certain parameters can be assessed by objective measurements collected from the industry or other sources [126]. Additionally, using single items to assess health-related outcomes increases the risk of response bias and limited possible comparisons between studies.

Numerous interventions included multiple heterogeneous components. Consequently, it is not possible to attribute the effectiveness of a particular intervention to one specific intervention component.

Some studies have reported long-term outcomes. However, the majority of studies have not used an intention-to-treat analyses or failed to report this in their publication. Thus, the generalizability of the reported results is uncertain, as it is unclear whether they exclusively apply to individuals who completed all the assessments. Additionally, the findings may have been influenced by selection bias.

Strengths of this review

This review provides a detailed analysis of workplace health promotion interventions among industrial workers. A narrative synthesis was selected, given the study objectives and high levels of heterogeneity. A strength of this review is that it reports workplace health promotion interventions and their beneficial or non-beneficial effects on health- and work-related outcomes, which limits potential bias. Not limiting the conditions of the population to specific health conditions has shown its applicability to society. Risk of bias and a detailed quality assessment was performed for each included study.

Recommendations for future research

This systematic review highlights several areas for future research to improve the effectiveness and reliability of workplace health promotion programs for industrial workers. One major consideration is the high heterogeneity in the parameters and interventions across the included studies. This variability can be attributed to differences in implementation fidelity, participant characteristics, and the specific context in which the interventions were applied. For instance, variations in intervention delivery, duration, intensity, and the baseline health status of participants could all contribute to the observed differences in effectiveness. However, only published studies were included. We need to acknowledge the possibility of publication bias, which may impact the findings.

Future research should include only valid and reliable measures of health-related outcomes. Furthermore, interventions may focus on improving the specific health characteristics of included industrial workers. In addition, work and leisure time, especially physical parameters, should be measured and, where possible, should be used with objective measurements. Furthermore, the issue of high drop-out rates reported in several studies is a concern that requires further investigation. To address this challenge, future research should focus on the feasibility and acceptance of different types of interventions. This approach will allow researchers and policymakers to determine the most suitable interventions for specific participants and organisations.

Future research should evaluate health-related outcomes at the end of the intervention and at regular follow-ups to determine whether any beneficial effects can be maintained, particularly for behavioural approaches. Furthermore, conducting long-term studies is essential to capture the impact of interventions throughout a more extended period of time. This might lead to a human-centred approach to promoting workplace health initiatives and principles such as the Goldilocks principle [127], which could result in the effective implementation of interventions. Despite recent research, there remains a need for well-designed studies to thoroughly assess the effectiveness of workplace health promotion interventions on health outcomes. Higher-quality studies are also necessary to enhance evidence transparency and support meta-analyses and study weighting [128]. Utilising randomisation, blinding techniques, and conducting predefined subgroup analyses can improve future research.

Conclusions

This systematic review provides an extensive overview on workplace interventions and their impact on industrial workers' health-related outcomes. Although the included studies provide evidence that workplace health promotion can be effective, the overall results are inconclusive. Beyond that, a high risk of bias for certain domains and a high overall risk of bias was revealed, and several methodological limitations in the current evidence-based research are given. The heterogeneity of interventions should be recognised in terms of general conclusions, and further research is needed to determine which elements are most likely to increase efficacy and adoption within the workplace setting. The specific health characteristics and conditions of industrial workers are important factors that must be considered. Consequently, drawing solid conclusions regarding the effectiveness of workplace interventions among industrial workers remain challenging. However, given the positive outcomes of some related studies, there is a strong need for implementing workplace interventions in industrial workers on the one hand, and for continuing research efforts to support national and global public health policies to improve industrial workers' health on the other hand.

List of abbreviations

BMI: Body mass index; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCT: Randomised controlled trials

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets used and analysed during the review are available from the corresponding author on reasonable quest.

Competing interests

The authors declare that they have no competing interests.

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Authors contributions

SJ was the lead author and contributed to the study design, screening process and eligibility process (as a reviewer), data extraction, and evaluation of methodological quality. SZ and LR contributed to the screening process and eligibility process (as reviewer) and methodological quality evaluation. LH, CB and DN critically revised the paper and intellectually contributed to it. JF was the study supervisor and contributed to the methodological quality evaluation (as a consultant reviewer) and revised the paper critically and intellectually contributed to it. All the authors have read and approved the final version of the manuscript.

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References

1. Moreira-Silva, I., et al., *The Effects of Workplace Physical Activity Programs on Musculoskeletal Pain: A Systematic Review and Meta-Analysis.* Workplace Health Saf, 2016. **64**(5): p. 210-22.
2. Prall, J. and M. Ross, *The management of work-related musculoskeletal injuries in an occupational health setting: the role of the physical therapist.* J Exerc Rehabil, 2019. **15**(2): p. 193-199.
3. Conn, V.S., et al., *Meta-analysis of workplace physical activity interventions.* Am J Prev Med, 2009. **37**(4): p. 330-9.
4. Kuster, A.T., et al., *Computer-based versus in-person interventions for preventing and reducing stress in workers.* Cochrane Database Syst Rev, 2017. **8**(8): p. Cd011899.
5. Freak-Poli, R., et al., *Workplace pedometer interventions for increasing physical activity.* Cochrane Database Syst Rev, 2020. **7**(7): p. CD009209.
6. Botwright, S., et al., *Which interventions for alcohol use should be included in a universal healthcare benefit package? An umbrella review of targeted interventions to address harmful drinking and dependence.* BMC Public Health, 2023. **23**(1): p. 382.
7. La Torre, G., et al., *Smoking cessation interventions on health-care workers: a systematic review and meta-analysis.* PeerJ, 2020. **8**: p. e9396.
8. Hakro, S. and L. Jinshan, *Workplace Employees' Annual Physical Checkup and During Hire on the Job to Increase Health-care Awareness Perception to Prevent Disease Risk: A Work for Policy-Implementable Option Globally.* Saf Health Work, 2019. **10**(2): p. 132-140.
9. Padula, R.S., et al., *Job rotation designed to prevent musculoskeletal disorders and control risk in manufacturing industries: A systematic review.* Applied Ergonomics, 2017. **58**: p. 386-397.
10. Smith, S.D., *Safety first? Production pressures and the implications on safety and health.* Construction Management and Economics, 2019. **37**(4): p. 238-242.
11. Burton, J. and W.H. Organization, *WHO healthy workplace framework and model: Background and supporting literature and practices*. 2010: World Health Organization.
12. Soler, R.E., et al., *A systematic review of selected interventions for worksite health promotion. The assessment of health risks with feedback.* Am J Prev Med, 2010. **38**(2 Suppl): p. S237-62.
13. Amatori, S., et al., *Short High-Intensity Interval Exercise for Workplace-Based Physical Activity Interventions: A Systematic Review on Feasibility and Effectiveness.* Sports Med, 2023. **53**(4): p. 887-901.
14. Grimani, A., E. Aboagye, and L. Kwak, *The effectiveness of workplace nutrition and physical activity interventions in improving productivity, work performance and workability: a systematic review.* BMC Public Health, 2019. **19**(1): p. 1676.
15. Bertera, R.L., *The effects of workplace health promotion on absenteeism and employment costs in a large industrial population.* Am J Public Health, 1990. **80**(9): p. 1101-5.
16. Campbell, M.K., et al., *Tailoring and targeting a worksite health promotion program to address multiple health behaviors among blue-collar women.* Am J Health Promot, 2000. **14**(5): p. 306-13.
17. Hoffmann, C., G. Stassen, and A. Schaller, *Theory-Based, Participatory Development of a Cross-Company Network Promoting Physical Activity in Germany: A Mixed-Methods Approach.* Int J Environ Res Public Health, 2020. **17**(23).

18. Minna, S. and N. Mika, *Relationship between construction workers' musculoskeletal disorders and occupational health service activities.* Work, 2012. **41** Suppl 1: p. 3753-6.
19. Quilling, E., et al., *State of evidence on municipal strategies for health promotion and prevention: a literature and database research (Scoping Review).* BMC Public Health, 2022. **22**(1): p. 301.
20. Chaiklieng, S. and P. Suggaravetsiri, *Low Back Pain (LBP) Incidence, Ergonomics Risk and Workers' Characteristics in Relations to LBP in Electronics Assembly Manufacturing.* Indian J Occup Environ Med, 2020. **24**(3): p. 183-187.
21. Sjogaard, G., et al., *The elixir of muscle activity and kinesiology in a health perspective: Evidence of worksite tailored exercise training alleviating muscle disorders.* J Electromyogr Kinesiol, 2021. **61**: p. 102600.
22. Buchvold, H.V., et al., *Associations between night work and BMI, alcohol, smoking, caffeine and exercise--a cross-sectional study.* BMC Public Health, 2015. **15**: p. 1112.
23. Manoogian, E.N.C., et al., *Feasibility of time-restricted eating and impacts on cardiometabolic health in 24-h shift workers: The Healthy Heroes randomized control trial.* Cell Metab, 2022. **34**(10): p. 1442-1456 e7.
24. Torquati, L., et al., *Shift Work and Poor Mental Health: A Meta-Analysis of Longitudinal Studies.* Am J Public Health, 2019. **109**(11): p. e13-e20.
25. Yang, S., et al., *Transformation to Industrial Artificial Intelligence and Workers' Mental Health: Evidence From China.* Front Public Health, 2022. **10**: p. 881827.
26. Saulle, R., et al., *Shift work, overweight and obesity in health professionals: a systematic review and meta-analysis.* Clin Ter, 2018. **169**(4): p. e189-e197.
27. Pega, F., et al., *Monitoring workers' health: focus on rights, determinants, and equity.* Lancet, 2023. **402**(10410): p. 1306-1308.
28. Damen, M.A.W., et al., *Factors associated with blue-collar workers' participation in Worksite Health Promotion Programs: a scoping literature review.* Health Promot Int, 2023. **38**(3).
29. Sundstrup, E., et al., *A Systematic Review of Workplace Interventions to Rehabilitate Musculoskeletal Disorders Among Employees with Physical Demanding Work.* J Occup Rehabil, 2020. **30**(4): p. 588-612.
30. Montano, D., H. Hoven, and J. Siegrist, *A meta-analysis of health effects of randomized controlled worksite interventions: does social stratification matter?* Scand J Work Environ Health, 2014. **40**(3): p. 230-4.
31. Brierley, M.L., et al., *The Effectiveness of Sedentary Behaviour Reduction Workplace Interventions on Cardiometabolic Risk Markers: A Systematic Review.* Sports Med, 2019. **49**(11): p. 1739-1767.
32. Lefebvre, C., et al., *Searching for and selecting studies*, in *Cochrane Handbook for Systematic Reviews of Interventions*. 2019. p. 67-107.
33. Bramer, W.M., et al., *Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study.* Systematic Reviews, 2017. **6**(1): p. 245.
34. Page, M.J., et al., *The PRISMA 2020 statement: an updated guideline for reporting systematic reviews.* Bmj, 2021. **372**: p. n71.
35. Berlin, C., et al. *A Systemic Overview of Factors Affecting the Cognitive Performance of Industrial Manual Assembly Workers*. in *Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021)*. 2021. Cham: Springer International Publishing.
36. Ouzzani, M., et al., *Rayyan-a web and mobile app for systematic reviews.* Syst Rev, 2016. **5**(1): p. 210.

37. Sterne, J., et al., *RoB 2: a revised tool for assessing risk of bias in randomised trials.* bmj, 2019. **366**.
38. Eldridge, S., et al., *Revised Cochrane risk of bias tool for randomized trials (RoB 2.0): additional considerations for cluster-randomized trials.* 2016.
39. McGuinness, L.A. and J.P.T. Higgins, *Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments.* Research Synthesis Methods, 2021. **12**(1): p. 55-61.
40. Hooper, P., et al., *Age-related macular degeneration and low-vision rehabilitation: a systematic review.* Can J Ophthalmol, 2008. **43**(2): p. 180-7.
41. Hootman, J.M., et al., *Reliability and validity of three quality rating instruments for systematic reviews of observational studies.* Res Synth Methods, 2011. **2**(2): p. 110-8.
42. Pescud, M., et al., *Employers' views on the promotion of workplace health and wellbeing: a qualitative study.* BMC Public Health, 2015. **15**: p. 642.
43. Rugulies, R., et al., *Work-related causes of mental health conditions and interventions for their improvement in workplaces.* Lancet, 2023. **402**(10410): p. 1368-1381.
44. Popay, J., et al., *Guidance on the conduct of narrative synthesis in systematic reviews.* A product from the ESRC methods programme Version, 2006. **1**(1): p. b92.
45. Aghilinejad, M., et al., *The effect of three ergonomics training programs on the prevalence of low-back pain among workers of an Iranian automobile factory: a randomized clinical trial.* The international journal of occupational and environmental medicine, 2014. **5**(2): p. 65-71.
46. Andersen, L.L., et al., *Psychosocial effects of workplace physical exercise among workers with chronic pain: Randomized controlled trial.* Medicine (Baltimore), 2017. **96**(1): p. e5709.
47. Asfar, T., et al., *Implementing a Novel Workplace Smoking Cessation Intervention Targeting Hispanic/Latino Construction Workers: A Pilot Cluster Randomized Trial.* Health Educ Behav, 2021. **48**(6): p. 795-804.
48. Brandt, M., et al., *Effects of a Participatory Ergonomics Intervention With Wearable Technical Measurements of Physical Workload in the Construction Industry: Cluster Randomized Controlled Trial.* J Med Internet Res, 2018. **20**(12): p. e10272.
49. Campbell, M.K., et al., *Effects of a tailored health promotion program for female blue-collar workers: health works for women.* Prev Med, 2002. **34**(3): p. 313-23.
50. Choi, H., et al., *The Effects of a Forest Therapy on Work-Related Stress for Employees in the Manufacturing Industry: Randomized Control Study.* Global Advances in Health and Medicine, 2022. **11**.
51. Cimarras-Otal, C., et al., *Adapted exercises versus general exercise recommendations on chronic low back pain in industrial workers: A randomized control pilot study.* Work, 2020. **67**(3): p. 733-740.
52. Comper, M.L.C., et al., *Effectiveness of job rotation for preventing work-related musculoskeletal diseases: a cluster randomised controlled trial.* Occup Environ Med, 2017. **74**(8): p. 545-552.
53. Pereira, C.C., R.F. Lopez, and R. Vilarta, *Effects of physical activity programmes in the workplace (PAPW) on the perception and intensity of musculoskeletal pain experienced by garment workers.* Work, 2013. **44**(4): p. 415-21.
54. Gajewski, P.D., G. Freude, and M. Falkenstein, *Cognitive Training Sustainably Improves Executive Functioning in Middle-Aged Industry Workers Assessed by Task Switching: A Randomized Controlled ERP Study.* Front Hum Neurosci, 2017. **11**: p. 81.
55. Gram, B., et al., *Occupational and leisure-time physical activity and workload among construction workers - a randomized control study.* Int J Occup Environ Health, 2016. **22**(1): p. 36-44.

56. Gupta, N., et al., *Effectiveness of a participatory physical and psychosocial intervention to balance the demands and resources of industrial workers: A cluster-randomized controlled trial.* Scand J Work Environ Health, 2018. **44**(1): p. 58-68.
57. Han, H.I., H.S. Choi, and W.S. Shin, *Effects of hamstring stretch with pelvic control on pain and work ability in standing workers.* J Back Musculoskelet Rehabil, 2016. **29**(4): p. 865-871.
58. Kaveh, M.H., et al., *Effectiveness of a transactional model-based education programme for enhancing stress-coping skills in industrial workers: a randomized controlled trial.* Sci Rep, 2023. **13**(1): p. 5076.
59. Lavender, S.A., E.P. Lorenz, and G.B. Andersson, *Can a new behaviorally oriented training process to improve lifting technique prevent occupationally related back injuries due to lifting?* Spine (Phila Pa 1976), 2007. **32**(4): p. 487-94.
60. Lowe, B.D., et al., *Evaluation of a Workplace Exercise Program for Control of Shoulder Disorders in Overhead Assembly Work.* J Occup Environ Med, 2017. **59**(6): p. 563-570.
61. Malkinson, R., T. Kushnir, and E. Weisberg, *Stress management and burnout prevention in female blue-collar workers: Theoretical and practical implications.* International Journal of Stress Management, 1997. **4**(3): p. 183-195.
62. Moreira-Silva, I., et al., *The effect of a physical activity program on decreasing physical disability indicated by musculoskeletal pain and related symptoms among workers: a pilot study.* Int J Occup Saf Ergon, 2014. **20**(1): p. 55-64.
63. Morgan, P.J., et al., *The impact of a workplace-based weight loss program on work-related outcomes in overweight male shift workers.* J Occup Environ Med, 2012. **54**(2): p. 122-7.
64. Mousavi, E., et al., *Investigating the effect of custom-made insoles and exercises on lower limb and back discomfort in assembly-line workers in a rubber tire factory: A randomized controlled trial.* Human Factors and Ergonomics in Manufacturing & Service Industries, 2019. **29**(6): p. 478-484.
65. Munoz-Poblete, C., et al., *Effectiveness of Workplace-Based Muscle Resistance Training Exercise Program in Preventing Musculoskeletal Dysfunction of the Upper Limbs in Manufacturing Workers.* J Occup Rehabil, 2019. **29**(4): p. 810-821.
66. Nabizadeh, S.M., et al., *Educational Intervention Based on Protection Motivation Theory to Improve Vitamin E and C Consumption among Iranian Factory Workers.* Journal of Clinical and Diagnostic Research, 2018. **12**(10): p. Jc1-Jc6.
67. Park, J.H., S.H. Lee, and D.S. Ko, *The Effects of the Nintendo Wii Exercise Program on Chronic Work-related Low Back Pain in Industrial Workers.* J Phys Ther Sci, 2013. **25**(8): p. 985-8.
68. Rasotto, C., et al., *A tailored workplace exercise program for women at risk for neck and upper limb musculoskeletal disorders: a randomized controlled trial.* J Occup Environ Med, 2015a. **57**(2): p. 178-83.
69. Rasotto, C., et al., *Tailored exercise program reduces symptoms of upper limb work-related musculoskeletal disorders in a group of metalworkers: A randomized controlled trial.* Man Ther, 2015b. **20**(1): p. 56-62.
70. Santos, H.G., et al., *Effectiveness of a progressive resistance exercise program for industrial workers during breaks on perceived fatigue control: a cluster randomized controlled trial.* BMC Public Health, 2020. **20**(1): p. 849.
71. Sene-Mir, A.M., et al., *Manual Material Handling Training: The Effect of Self-Observation, Hetero-Observational and Intrinsic Feedback on Workers' Knowledge and Behaviour.* Int J Environ Res Public Health, 2020. **17**(21): p. 1-19.

72. Sertel, M., F.D. Üçsular, and Ü. Uğurlu, *The effects of worksite exercises on physical capabilities of workers in an industry of a developing country: A randomized controlled study.* Isokinetics and Exercise Science, 2016. **24**(3): p. 247-255.
73. Sundstrup, E., et al., *Effect of two contrasting interventions on upper limb chronic pain and disability: a randomized controlled trial.* Pain Physician, 2014a. **17**(2): p. 145-54.
74. Sundstrup, E., et al., *Strength Training Improves Fatigue Resistance and Self-Rated Health in Workers with Chronic Pain: A Randomized Controlled Trial.* Biomed Res Int, 2016. **2016**: p. 4137918.
75. Sundstrup, E., et al., *Workplace strength training prevents deterioration of work ability among workers with chronic pain and work disability: a randomized controlled trial.* Scand J Work Environ Health, 2014b. **40**(3): p. 244-51.
76. Sutarto, A.P., M.N. Wahab, and N.M. Zin, *Resonant breathing biofeedback training for stress reduction among manufacturing operators.* Int J Occup Saf Ergon, 2012. **18**(4): p. 549-61.
77. Viester, L., et al., *The effect of a health promotion intervention for construction workers on work-related outcomes: results from a randomized controlled trial.* Int Arch Occup Environ Health, 2015. **88**(6): p. 789-98.
78. Weidman, J., D. Dickerson, and C. Koebel, *Effective Intervention Strategy to Improve Worker Readiness to Adopt Ventilated Tools.* Journal of Construction Engineering and Management, 2016. **142**: p. 04016028.
79. Yu, I.T., et al., *Effectiveness of participatory training in preventing accidental occupational injuries: a randomized-controlled trial in China.* Scand J Work Environ Health, 2017. **43**(3): p. 226-233.
80. Yu, W., et al., *Effectiveness of participatory training for prevention of musculoskeletal disorders: a randomized controlled trial.* Int Arch Occup Environ Health, 2013. **86**(4): p. 431-40.
81. Gram, B., et al., *Effect of individualized worksite exercise training on aerobic capacity and muscle strength among construction workers--a randomized controlled intervention study.* Scand J Work Environ Health, 2012. **38**(5): p. 467-75.
82. Gram, B., et al., *Does an exercise intervention improving aerobic capacity among construction workers also improve musculoskeletal pain, work ability, productivity, perceived physical exertion, and sick leave?: a randomized controlled trial.* J Occup Environ Med, 2012. **54**(12): p. 1520-6.
83. Nurminen, E., et al., *Effectiveness of a worksite exercise program with respect to perceived work ability and sick leaves among women with physical work.* Scandinavian Journal of Work Environment & Health, 2002. **28**(2): p. 85-93.
84. Sertel, M., F.D. Ucsular, and U. Ugurlu, *The effects of worksite exercises on physical capabilities of workers in an industry of a developing country: A randomized controlled study.* Isokinetics and Exercise Science, 2016. **24**(3): p. 247-255.
85. Krungkraipetch, N., et al., *Interventions to prevent musculoskeletal disorders among informal sector workers: a literature review.* Southeast Asian J Trop Med Public Health, 2012. **43**(2): p. 510-25.
86. Chu, A.H., et al., *Do workplace physical activity interventions improve mental health outcomes?* Occup Med (Lond), 2014. **64**(4): p. 235-45.
87. Martin, A., K. Sanderson, and F. Cocker, *Meta-analysis of the effects of health promotion intervention in the workplace on depression and anxiety symptoms.* Scandinavian Journal of Work, Environment & Health, 2009(1): p. 7-18.
88. Eddy, K., Z. Jordan, and M. Stephenson, *Health professionals' experience of teamwork education in acute hospital settings: a systematic review of qualitative literature.* JBI Database System Rev Implement Rep, 2016. **14**(4): p. 96-137.

89. Verweij, L.M., et al., *Meta-analyses of workplace physical activity and dietary behaviour interventions on weight outcomes.* Obes Rev, 2011. **12**(6): p. 406-29.
90. Battams, S., et al., *Workplace risk factors for anxiety and depression in male-dominated industries: a systematic review.* Health Psychol Behav Med, 2014. **2**(1): p. 983-1008.
91. Tam, G. and M.P.S. Yeung, *A systematic review of the long-term effectiveness of work-based lifestyle interventions to tackle overweight and obesity.* Prev Med, 2018. **107**: p. 54-60.
92. Fauzan, N.S., et al., *A Systematic Literature Review of the Factors Influencing Hearing Protection Device Usage among Industrial Workers.* Int J Environ Res Public Health, 2023. **20**(4).
93. Dabkowski, E., et al., *A systematic literature review of workplace physical activity programs: an exploration of barriers and enabling factors.* Cogent Psychology, 2023. **10**(1).
94. Burn, N.L., et al., *Effects of Workplace-Based Physical Activity Interventions on Cardiorespiratory Fitness: A Systematic Review and Meta-Analysis of Controlled Trials.* Sports Med, 2019. **49**(8): p. 1255-1274.
95. Kwak, L., et al., *Promoting physical activity and healthy dietary behavior: the role of the occupational health services: a scoping review.* J Occup Environ Med, 2014. **56**(1): p. 35-46.
96. Stanulewicz, N., et al., *Effectiveness of Lifestyle Health Promotion Interventions for Nurses: A Systematic Review.* Int J Environ Res Public Health, 2019. **17**(1).
97. Jirathananuwat, A. and K. Pongpirul, *Promoting physical activity in the workplace: A systematic meta-review.* J Occup Health, 2017. **59**(5): p. 385-393.
98. Bezzina, A., et al., *Workplace Health Promotion Programs Targeting Smoking, Nutrition, Physical Activity, and Obesity in Men: A Systematic Review and Meta-Analysis of Randomized Controlled Trials.* Health Educ Behav, 2024. **51**(1): p. 113-127.
99. Ekblom-Bak, E., et al., *Revisiting the physical activity paradox: the role of cardiorespiratory fitness in workers with high aerobic demands.* Scand J Public Health, 2024. **52**(2): p. 123-127.
100. Gritzka, S., et al., *The Effects of Workplace Nature-Based Interventions on the Mental Health and Well-Being of Employees: A Systematic Review.* Front Psychiatry, 2020. **11**: p. 323.
101. Proper, K.I. and S.H. van Oostrom, *The effectiveness of workplace health promotion interventions on physical and mental health outcomes - a systematic review of reviews.* Scand J Work Environ Health, 2019. **45**(6): p. 546-559.
102. Rudolph, C.W., L.D. Murphy, and H. Zacher, *A systematic review and critique of research on "healthy leadership".* Leadership Quarterly, 2020. **31**(1): p. 21.
103. Heine, M., et al., *Developing a Complex Understanding of Physical Activity in Cardiometabolic Disease from Low-to-Middle-Income Countries-A Qualitative Systematic Review with Meta-Synthesis.* Int J Environ Res Public Health, 2021. **18**(22): p. 11977.
104. Bezzina, A., et al., *Workplace Psychosocial Factors and Their Association With Musculoskeletal Disorders: A Systematic Review of Longitudinal Studies.* Workplace Health Saf, 2023. **71**(12): p. 578-588.
105. Sun, M., et al., *Meta-analysis on shift work and risks of specific obesity types.* Obes Rev, 2018. **19**(1): p. 28-40.
106. Madden, S.K., et al., *The effect of workplace lifestyle programmes on diet, physical activity, and weight-related outcomes for working women: A systematic review using the TIDieR checklist.* Obes Rev, 2020. **21**(10): p. e13027.

107. Cahill, K. and T. Lancaster, *Workplace interventions for smoking cessation.* Cochrane Database Syst Rev, 2014(2): p. Cd003440.
108. Malik, S.H., H. Blake, and L.S. Suggs, *A systematic review of workplace health promotion interventions for increasing physical activity.* Br J Health Psychol, 2014. **19**(1): p. 149-80.
109. Goldgruber, J. and D. Ahrens, *Effectiveness of workplace health promotion and primary prevention interventions: a review.* Journal of Public Health, 2009. **18**(1): p. 75-88.
110. Groeneveld, I.F., et al., *Lifestyle-focused interventions at the workplace to reduce the risk of cardiovascular disease--a systematic review.* Scand J Work Environ Health, 2010. **36**(3): p. 202-15.
111. Mänttäri, S., et al., *Interventions to promote work ability by increasing physical activity among workers with physically strenuous jobs: A scoping review.* Scand J Public Health, 2021. **49**(2): p. 206-218.
112. Guo, H.R., et al., *Prevalence of musculoskeletal disorder among workers in Taiwan: a nationwide study.* J Occup Health, 2004. **46**(1): p. 26-36.
113. Jaffar, N., et al., *A Literature Review of Ergonomics Risk Factors in Construction Industry.* Procedia Engineering, 2011. **20**: p. 89-97.
114. Javanmardi, S., et al., *Impact of work pace on cardiorespiratory outcomes, perceived effort and carried load in industrial workers: a randomised cross-over trial.* Occup Environ Med, 2024. **81**(9): p. 456-461.
115. Lie, A., et al., *Occupational noise exposure and hearing: a systematic review.* Int Arch Occup Environ Health, 2016. **89**(3): p. 351-72.
116. Wang, D., F. Dai, and X. Ning, *Risk Assessment of Work-Related Musculoskeletal Disorders in Construction: State-of-the-Art Review.* Journal of Construction Engineering and Management, 2015. **141**(6): p. 04015008.
117. Dias, M., et al., *Cardiovascular load assessment in the workplace: A systematic review.* International Journal of Industrial Ergonomics, 2023. **96**: p. 103476.
118. Liu, B.P. and C.X. Jia, *Shift work schedule and sleep patterns in relation to incident depression: Evidence from a prospective cohort study.* Psychiatry Res, 2023. **321**: p. 115076.
119. Santana, A.I.C., et al., *Association between metabolic syndrome and work: an integrative review of the literature.* Rev Bras Med Trab, 2020. **18**(2): p. 185-193.
120. Seaverson, E.L.D., et al., *Measuring Participation in Employer-Sponsored Health and Well-Being Programs: A Participation Index and Its Association With Health Risk Change.* Am J Health Promot, 2019. **33**(7): p. 1002-1008.
121. Diaconu, K., et al., *Methods for medical device and equipment procurement and prioritization within low- and middle-income countries: findings of a systematic literature review.* Global Health, 2017. **13**(1): p. 59.
122. Rojatz, D., A. Merchant, and M. Nitsch, *Factors influencing workplace health promotion intervention: a qualitative systematic review.* Health Promot Int, 2017. **32**(5): p. 831-839.
123. Kiviniemi, M.T. and A.J. Rothman, *What do people think about changes in health behaviors? Differential perceptions of consequences of increases and decreases in health behaviors.* Psychology & Health, 2008. **23**(7): p. 867-885.
124. Higgins, J.P.T., et al., *Assessing risk of bias in a randomized trial*, in *Cochrane Handbook for Systematic Reviews of Interventions*. 2019. p. 205-228.
125. Niederer, D., M. Weippert, and M. Behrens, *What Modifies the Effect of an Exercise Treatment for Chronic Low Back Pain? A Meta-epidemiologic Regression Analysis of Risk of Bias and Comparative Effectiveness.* J Orthop Sports Phys Ther, 2022. **52**(12): p. 792-802.

126. Lamsal, R., et al., *Paid Sick Leave and Healthcare Utilization in Adults: A Systematic Review and Meta-analysis.* Am J Prev Med, 2021. **60**(6): p. 856-865.
127. Holtermann, A., S.E. Mathiassen, and L. Straker, *Promoting health and physical capacity during productive work: the Goldilocks Principle.* Scand J Work Environ Health, 2019. **45**(1): p. 90-97.
128. Vali, Y., M.M.G. Leeflang, and P.M.M. Bossuyt, *Application of weighting methods for presenting risk-of-bias assessments in systematic reviews of diagnostic test accuracy studies.* Systematic Reviews, 2021. **10**(1): p. 191.

Publication 2: Impact of work pace on cardiorespiratory outcomes, perceived effort, and carried load in industrial workers: A randomized crossover trial

Javanmardi, Sasha[1], Rappelt, Ludwig[1,2], Heinke, Lars[1], Niederer, Daniel[1], Zemke, Janis Alexander[1], Freiwald, Jürgen[1], Baumgart, Christian[1]

[1] Department of Movement and Training Science, University of Wuppertal, Wuppertal, Germany

[2] Department of Intervention Research in Exercise Training, German Sport University Cologne, Cologne, Germany

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Abstract

Objectives: This study investigates the impact of different work paces on cardiorespiratory outcomes, perceived effort, and carried load in industrial workers.

Methods: A randomised crossover trial was conducted at a mid-sized steel company. We included twelve healthy industrial workers (8 females, age: mean 44 ± standard deviation 9 years, height: 1.70 ± 0.08 m, body mass: 79.5 ± 13.4 kg) with at least six months of working experience. All participants performed 5 minutes of piece work at 100% (P100), 115% (P115), and 130% (P130) of the company's internal target yielded in a randomised order, separated by five-minute familiarization breaks. The primary outcome was energy expenditure (EE), calculated from a respiratory gas exchange using a metabolic analyser. Secondary outcomes were total ventilation ($\dot{V}E$), oxygen uptake (VO_2), carbon dioxide release ($\dot{V}CO_2$), respiratory exchange ratio (RER), heart rate (HR), and perceived effort (RPE; 0-10). Furthermore, the metabolic equivalent (MET) and the carried load (CL) were calculated. Data were analyzed with rANOVAs.

Results: For EE, a large "pace" effect with a small difference between P100 and P130 (165.9 ± 33.4 vs 178.8 ± 40.1 kcal/h^{-1}, $p = 0.008$, SMD = 0.35) was revealed. Additionally, a large difference in CL between all paces ($p < 0.001$, SMD ≥ 1.10) was revealed. No adverse events occurred.

Conclusions: Cardiorespiratory outcomes rise with increased work pace, but the practical relevance of these differences still needs to be specified. However, the carried load will add up over time and may impact musculoskeletal health in the long term.

Keywords

work condition, workplace health promotion, musculoskeletal disorders, physical demands, ergonomics, energy demand

What is already known on this topic

Industrial workers face physical and mental loads including repetitive tasks and a high pace of work. Conflicting results exist regarding the impact of work pace on various factors, such as error rate, biomechanical exposure, muscular load, musculoskeletal disorders, and subjective experiences, such as perceived exertion and perceived fatigue.

What this study adds

Higher work pace increases cardiorespiratory factors and carried load among industrial workers, but does not affect perceived effort and heart rate. Carried load should be highlighted because of potential long-term musculoskeletal health implications and emphasizing the need to prioritize workplace health and productivity.

How this study might affect research, practice or policy

Work pace needs to be included in future research or interventions to enhance occupational health and safety through organizational changes, such as job rotation or a worker-specific change. This study emphasizes the significant impact of work pace on workers' physiological responses and musculoskeletal health.

Introduction

Industrial workers are exposed to physical hazards during work, including heavy lifting, awkward positions, vibrations, high temperatures, precision, noise, excessive work pace, and repetitive work [1, 2]. In this context, more than 60% of industrial workers perform repetitive movements in standard tasks with cycle times of less than 30 seconds and minimal variation [3].

Although a high work pace may not necessarily lead to greater profitability [4, 5], it is considered the standard practice within the industry. During repetitive tasks, work pace can affect performance [6, 7] and impact the well-being and productivity of workers [8]. Beyond that, a high work pace increases error rate [6, 7] and perceived exertion [9]. Overall, the effect of work pace on biomechanical exposure is conflicting [9], revealing a higher muscular load [3] and a potential increased risk of musculoskeletal disorders [8]. While work pace does not affect upper extremity kinematics [10], an increased work pace can add time spent in awkward postures [11] and may lead to fatiguing effects [6].

To better understand the link between occupational risks and work-related diseases, workplace-specific assessments of physical load on the cardiovascular system are warranted [2]. Determining energy demand during work may be crucial for occupational health monitoring [12]. The influence of work pace on cardiorespiratory factors has not been fully considered yet. Based on such assessments, customized health promotion interventions can be developed to address industrial workers' specific needs and challenges on environmental and individual levels. This can improve the long-term success of workplace health promotion [13]. Therefore, this study investigated the impact of different work paces on cardiorespiratory factors, perceived effort, and carried load in industrial workers. We hypothesized that the higher the work pace, the higher the perceived, cardiorespiratory, and carried load.

Methods

Trial design and ethical aspects

We adopted a randomised crossover study design. The trial was designed and conducted in accordance with the Declaration of Helsinki and was approved by the local ethical committee of the University of Wuppertal (SK/AE 240306). All participants provided written informed consent before the start of the study. No changes to methods after trial commencement was undertaken.

Participants

Assuming large effect sizes [4], the power analysis ($\alpha = 0.05$, study power (1-β-error) = 0.80, r = 0.5, effect size $\eta_p^2 = 0.14$ (f = 0.40)), with G*Power (Version 3.1.9.7, University of Düsseldorf, Germany), revealed a required sample size of n = 12 participants.

Factory workers from a mid-size steel company in Germany were enrolled in this acute intervention study. Prior to the study, 26 factory workers (16 females) were asked to participate in an informational event voluntarily. Consequently, 12 (8 females) respondents who met the selection criteria were recruited. The inclusion criteria were as follows: (I) age > 17 years, (II) working experience at the respective workstation for at least 6 months. Exclusion criteria included (III) no cardiovascular or metabolic diseases (e.g. diabetes mellitus) and (IV) no acute or chronic skin diseases or injuries. Participants were instructed to avoid strenuous physical exercise 24h before their study attendance.

Randomisation

Eligible participants were randomly assigned to three different work paces. The randomisation process was simple non restricted and was performed by SJ using the *sample*-function in R (version 4.0.5) and RStudio (version 1.4.1106). All participants were blinded against the randomisation-sequence.

Interventions

All participants performed repetitive tasks sitting at one of three similar working stations in the production process of pliers, which involved inserting pliers into a station to process the tongs and then removing them. A comparable amount of product was processed at each of the three working stations, with individual pieces of material weighing 200g per piece. For 10 minutes each, participants processed a predetermined predefined number of products at rates corresponding to 100% (P100), 115% (P115), and 130% (P130) of the normative piece rate based on internal company calculations. Five of the ten minutes were dedicated to familiarization, while the remaining five minutes were used for data collection. Participants were given feedback every minute on the number of workpieces handled in the previous minute and instructed to maintain, increase, or decrease their work pace to match the predefined rate (Table 7). Throughout the whole test, heart rate (H9, Polar Electro, Kempele, Finnland) and respiratory gas exchange were continuously reported. Respiratory gas exchange was spirometrically assessed breath-by-breath using a validated metabolic analyser (Metamax 3b, Cosmed, Germany). Before each measurement, the spirometric system was calibrated according to the manufacturer's recommendations.

Table 7: Target and Reached Work productivity at the three different levels of production standard time (P100, P115, P130).

Condition	Work Productivity Target (%)	Work Productivity Reached (%)	Work Productivity Target (Quantity/min)	Work Productivity Reached (Quantity/min)
P100	100	101.2 ± 3.8	14.4 ± 1.4	14.5 ± 1.4
P115	115	113.0 ± 4.0	16.5 ± 1.7	16.2 ± 1.7
P130	130	128.6 ± 3.5	18.7 ± 1.9	18.5 ± 1.8

Primary outcome

The primary outcome measurement was energy expenditure (EE; in kcal/h^{-1}). To determine EE, carbon dioxide output ($\dot{V}CO_2$) and oxygen uptake ($\dot{V}O_2$) were utilized, according to the equation of Weir [14] as the total heat output in a given time [kcal] = 3.941 $\dot{V}O_2$ [l] + 1.106 $\dot{V}CO_2$ [l].

Secondary Outcomes

The secondary outcomes were heart rate, total ventilation volume ($\dot{V}E$; in l/min^{-1}), carbon dioxide output ($\dot{V}CO_2$; in l/min^{-1}), oxygen uptake ($\dot{V}O_2$; in l/min^{-1}), respiratory exchange ratio (RER; calculated by dividing $\dot{V}CO_2$ by $\dot{V}O_2$), averaged over the last five minutes for each of the three working paces. Furthermore, $\dot{V}O_2$ related to the body weight and divided by 3.5 was used to estimate the metabolic equivalent (MET) of the performed tasks [15]. Moreover, the carried load (CL; in kg) was assessed by counting the products' total number and rate (pieces per minute). After completing each bout, the participants were asked to rate their perceived effort (RPE) from 0 (lowest) to 10 (highest) [16]. No changes were undertaken after trial commenced.

Statistics

All data are presented as mean ± standard deviation. Normal distribution was verified via the Shapiro–Wilk test ($p \geq 0.1$), and residuals were investigated using Q–Q plots. Variance homogeneity was verified using Levene-tests ($p \geq 0.1$). To examine “pace” differences (P100 vs. P115 vs. P130), repeated measure analyses of variance (rANOVA) were conducted for all respective outcome measures (EE, $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E$, RER, MET, HR, RPE and carried load). Mauchly’s test for sphericity was performed, and Greenhouse-Geisser corrections (GG) were applied if necessary ($p \geq 0.05$). The rANOVA effect sizes are given as partial eta squared (η_p^2), with ≥0.01, ≥0.06, and ≥0.14, indicating small, moderate, and large effects, respectively [17]. In the case of significant “pace” effects, Bonferroni-corrected post-hoc tests were subsequently computed. For pairwise effect size comparison, standard mean differences (SMD) were calculated, with <0.2, 0.2 ≤-<0.5, 0.5 ≤-<0.8, ≥0.8, indicating small, moderate, and large effects, respectively [17]. All statistical analyses were conducted using R (version 4.0.5) and RStudio (version 1.4.1106) software.

Results

12 participants were enrolled in August 2023 (8 females and 4 males, age: 44 ± 9 years, height: 1.70 ± 0.08 m, body mass: 79.5 ± 13.4 kg). No participant withdrew consent; none had to be excluded. Due to technical problems, the heart rate of two participants could not be recorded. For each additional outcome and condition, the data of all 12 participants could be used. During study conduction, no adverse or serious adverse event occurred.

The analysis revealed a large and significant “pace” effect in EE ($F(2, 22) = 5.78$, $p = 0.010$, $\eta_p^2 = 0.34$). Post-hoc testing indicated a significant difference between P100 and P130 (165.9 ± 33.4 vs. 178.8 ± 40.1 kcal/h^{-1}, $p = 0.008$, SMD = 0.35). In addition, a large and significant “pace” effect occurred for MET ($F(2, 22) = 6.03$, $p = 0.008$, $\eta_p^2 = 0.35$) with post-hoc significant difference between P100 and P130 (1.75 ± 0.39 vs. 1.89 ± 0.34 METs, $p = 0.007$, SMD = 0.38). The values are depicted in Figure 6.

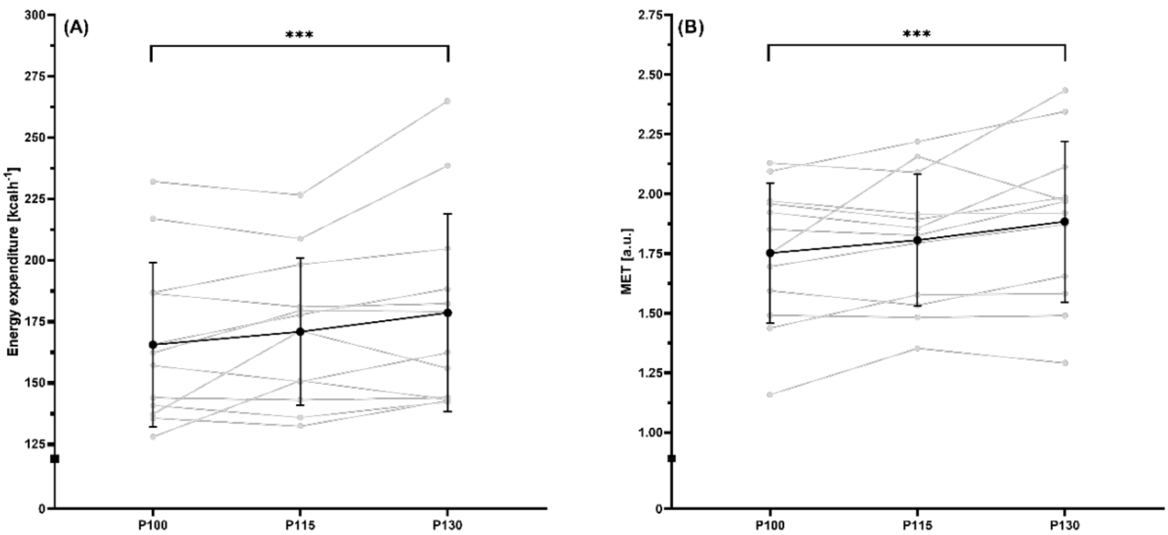

Figure 6: Mean values (black dots) ± standard deviation (error bars) for (A) energy expenditure and (B) metabolic equivalent of task (MET) during three different levels of production standard time (P100, P115, P130). Furthermore, individual values are indicated in grey). ***Significantly different from one another ($p < 0.001$).

Furthermore, a large and significant “pace” effect for $\dot{V}E$ ($F(2, 22) = 3.68$, $p = 0.042$, $\eta_p^2 = 0.25$), $\dot{V}O_2$ ($F(2, 22) = 6.21$, $p = 0.007$, $\eta_p^2 = 0.36$), $\dot{V}CO_2$ ($F(2, 22) = 4.32$, $p = 0.026$, $\eta_p^2 = 0.28$). The results of post-hoc testing revealed a significant difference between P100 and P130 in $\dot{V}E$ (15,95 ± 2.80 vs 17,12 ± 3.29 l/min-1, p = 0.041, SMD = 0.38), $\dot{V}O_2$ (0.48 ± 0.10 vs 0.52 ± 0.12 l/min^{-1}, p =0.006, SMD = 0,35), and $\dot{V}CO_2$ (0.43 ± 0.09 vs 0.46 ± 0.11 l/min^{-1}, p = 0.023, SMD = 0.19) but not between P115 and any of the other paces. For RER (F(2, 22) = 0.41, p = 0.669, η_p^2 = 0.04), HR (F(2, 18) = 1.15, p = 0.340, η_p^2 = 0.11) and RPE (F(2, 22) = 0.42, p = 0.660, η_p^2 = 0.04), no significant "pace" effect was detected. All underlying values are descriptively displayed in Table 8.

Table 8: Comparison of cardiorespiratory performance parameters and perceived effort during three different levels of production standard time (P100, P115, P130). Furthermore, F-Test p-values (1 × 3-rANOVA) and effect sizes (η_p^2, partial eta squared) are also provided.

Parameter	P100	P115	P130	*p*-value	η_p^2
$\dot{V}E$ (l/min^{-1})	15.95 ± 2.80	16.69 ± 2.53	17.12 ± 3.29*	0.042	0.25
$\dot{V}O_2$ (l/min^{-1})	0.48 ± 0.10	0.50 ± 0.09	0.52 ± 0.12**	0.007	0.36
$\dot{V}CO_2$ (l/min^{-1})	0.43 ± 0.09	0.45 ± 0.08	0.46 ± 0.11*	0.026	0.28
RER (a.u.)	0.89 ± 0.04	0.89 ± 0.03	0.89 ± 0.04	0.669	0.04
HR (min^{-1})	78.0 ± 10.6	81.9 ± 9.5	77.5 ± 14.2	0.340	0.11
RPE (a.u.)	3.6 ± 2.7	4.3 ± 2.1	3.9 ± 2.6	0.660	0.04

HR = heart rate, RER = respiratory exchange ratio, RPE = rating of perceived effort (1-10), $\dot{V}E$ = total ventilation, $\dot{V}O_2$ = acute oxygen uptake, $\dot{V}CO_2$ = acute carbon dioxide release, *Significantly higher than P100 ($p < 0.05$), **Significantly higher than P100 ($p < 0.01$).

Lastly, we found a large "pace" effect for the carried load (F(2, 22) = 145.02, $p < 0.001$, η_p^2 = 0.93). Post-hoc revealed lower carried load for P100 compared to P115 with a significantly large difference (174.2 ± 16.7 vs. 194.6 ± 20.5 kg/h^{-1}, $p < 0.001$, SMD = 1.10), for P100 compared to P130 (174.2 ± 16.7 vs. 221.4 ± 22.1 kg/h^{-1}, $p < 0.001$, SMD = 2.43), as well as a lower carried load for P115 compared to P130 (194.6 ± 20.5 vs. 221.4 ± 22.1 kg/h^{-1}, $p < 0.001$, SMD = 1.26.). The values are depicted in Figure 7.

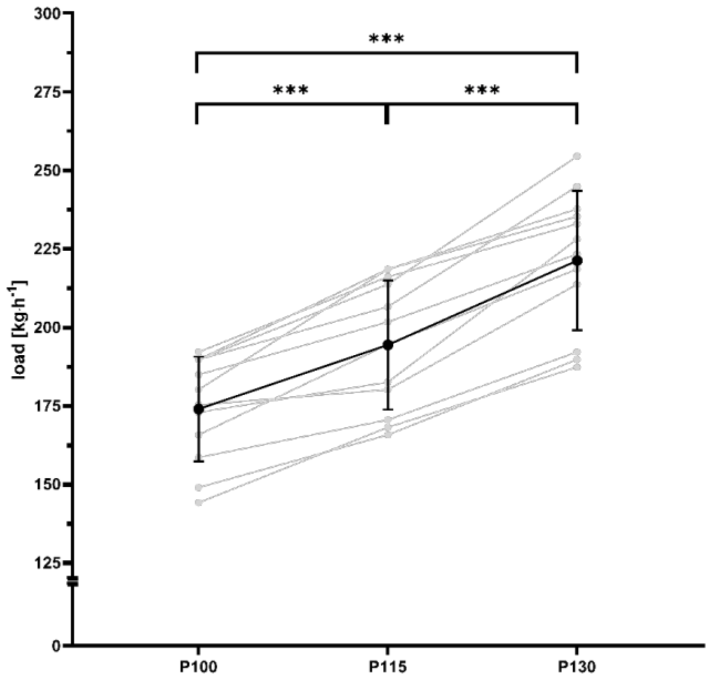

Figure 7: Mean values (black dots) ± standard deviation (error bars) for the carried load during the different levels of production standard time (P100, P115, and P130). Furthermore, individual values are indicated in grey. ***Significantly different from one another ($p < 0.001$).

Discussion

Main findings and hypothesis verification

This randomised crossover study elucidated the effect of different work paces on cardiorespiratory outcomes. In addition, the impact on carried load and subjective exertion was also assessed. The primary findings of this study were as follows: (I) EE, MET, $\dot{V}E$, $\dot{V}O_2$, and $\dot{V}CO_2$ increase with a higher work pace. (II) RPE did not change with different workpaces. (III) The carried load increase with higher work pace. The hypothesis could thus be confirmed for the cardiorespiratory and carried load outcomes but not for perceived loads.

Energy expenditure

The literature specifies an average energy expenditure of approximately 228 $kcal/h^{-1}$ for manufacturing workers, which is much higher than our measured energy expenditure. Our measurements are comparable to data from 1963, where the same amount of work was classified as light to moderate work grades with a range of 110-180 $kcal/h^{-1}$ [18].

We found a difference in energy expenditure between P100 and P130 of about 8%. This suggests that energy expenditure increases with higher work paces, which generally aligns with other studies [4, 19]. A study observed an increase of over 30% at a 29% higher work rate compared to a normal pace and about a 15% increase for a higher pace rate of 23%, measured with wearables [4]. In this study, 20 workers performed repetitive tasks connecting two components at a work pace of about 140%. Li and colleagues [19] investigated eight construction workers and found that an increased work pace resulted in higher energy expenditure when performing repetitive box handling at double their usual work pace (165.9 vs. 178.8 $kcal/h^{-1}$) [19]. This intake is lower than that observed in cleaners, averaging over all tasks about 213 $kcal/h^{-1}$ [11]. However, comparisons between the studies and our own should be approached cautiously, considering their respective job profiles. Undertaking repetitive tasks is associated with a high cognitive load, which impacts cycle times [20]. In addition, working in a sitting position may lead to reduced overall physical activity [21].

Workload

The workload classification must be considered when considering health promotion treatments for physical activity [22]. Thus, we determined that both P100 and P130 had MET values ranging from 1.75 to 1.89. This implies that the tasks are comparable to sedentary activities, such as hand sewing, and inactivity [23]. It is important to note that the MET value is considerably lower than that of activities requiring light or moderate exertion using machine tools, with a MET value of 3.0 [23]. Thus, based on these results and further research on health-related physical activity, engaging in leisure-time physical activity could benefit workers operating on these workstations to maintain their health [24].

Cardiorespiratory outcomes

Previous research has demonstrated an impact of performance intensity on heart rate [25]. We found no significant difference in heart rate across the different work paces. Looking only at the average heart rate values, the physical workload of all three conditions may be classified as light work [2]. Working in a sitting position can theoretically increase upper body activation without significantly raising heart rate. However, this remains uncertain as we haven't conducted any biomechanical assessment in our study. Nevertheless, in contrast to our findings, one study observed an increased heart rate at a higher work pace [4]. Despite the target work pace being set at approximately 140%, workers achieved a pace of approximately 129% [4]. In our study, every worker achieved a pace of 130% without difficulty. These findings suggest that our repetitive work was not metabolically demanding and did not consistently increase the heart rate. Furthermore, Nur and colleagues [4] used an ActiHeart monitoring device, whereas we used a heart rate monitor fitted with a chest strap. Although the AcitHeart device showed good validity in measuring heart rate, it had poor to moderate validity for energy expenditure. In fact, when compared to the spirometry system of our study, the ActiHeart device overestimated energy expenditure [26]. Therefore, it is crucial to consider the measuring instrument being used carefully.

Perceived effort

Although a positive effect between higher work pace and increased RPE ratings has been reported earlier [19], we did not find a significant difference between RPE at the three work paces. Specifically, we identified the highest RPE rating at 115%, diverging from the anticipated trend. Therefore, we could not rule out any bias. Our observed RPE rating remained consistently low, ranging between 3.6 and 4.3 on average, at different work paces. This is noteworthy compared to previous research reporting an RPE rating of 8–11.5 among cleaners with different tasks on a scale from 6 to 20 [22]. In this term, measuring an individual's RPE and well-being determines the internal load one experiences while dealing with external load demands [27]. Notably, an increased perceived exertion despite an improved physical condition may lead to a higher risk of musculoskeletal disorders [28].

Various exposure assessments are available to measure health-related outcomes using objective and subjective metrics like perceived effort [1, 2]. Self-reports are more accessible, less costly, and have shown to be a valid source of risk identification [1, 2]. Self-reports offer practical and economic advantages, and a large number of workers can participate [1]. Still, they are prone to bias through individual factors like pain affecting the perceived workload [29], undermining the reliability of this method in comparison to objective measurement and advanced techniques like sensors [1, 2]. However, significant associations between high perceived exertion assessed and cardiovascular parameters like $VO2_{max}$ or muscle load were demonstrated in lifting tasks [29]. Additionally, the frequency of the measurements varies between objective and subjective measurements potentially leading to bias [29]. In our study, we conducted breath-by-breath measurements for objective data and utilized subjective measurements covering a longer period of time.

Carried load

For the carried load, we found large effects between the three different work paces. Although the load with 200g is relatively low, the difference between P100 and P130 extrapolated to a 40-hour workweek can amount to over 1.8 tons per week. When repeated over time, this can increase the risk of musculoskeletal disorders, which are common and are one of the main health risks for industrial workers [3, 10]. Nevertheless, in our considerations, we assumed a constant speed throughout the day. Yet, it has already been shown that in many industries where employees are paid piece-work, employees are often working very fast in the morning, and the work speed decreases during day [30]. Therefore, developing strategies for identifying musculoskeletal issues and providing feasible solutions is essential. These may include well-organized duty schedules, modified working postures, job rotation, and preliminary training to manage these issues effectively [31]. However, it is essential to thoroughly evaluate potential solutions before implementing them, as they may not always be effective [32]. Research suggests that including workers' characteristics in solutions, such as flexible time constraints, can reduce hazardous effects on older workers [33]. Another solution might be an educational approach, as previous research has shown decreased muscle activity through ergonomic instructions [34]. Notably, psychosocial factors need to be considered as factors for musculoskeletal disorders [35] and workability [36].

Practical relevance

This study offers valuable insights for practical applications and suggests directions for future research. Research demonstrates that work pace varies throughout the day [6]. Although our study measured work pace for only a short period of time, the data indicates that work pace is a crucial factor to consider as an additional environmental factor in a human-centered approach to workplace health promotion initiatives. This aligns with principles such as the Goldilocks principle [37], which addresses the need for adequate recovery and highlights the balance between work capacity and promotion and maintenance of health.

Strengths and limitations

In our research, a strength was that we used a randomised crossover as the study design. Thus, the workplace posture does not greatly impact the results. This is important because a higher workspace may result in different postures [7], thus affecting energy expenditure [38]. In addition, studies have assumed that exposure to awkward posture leads to a high risk of musculoskeletal disorders [11]. In addition, our study relies predominantly on physically demanding tasks, and factors such as training status do not greatly impact our results, which can influence the measurement [2]. A limitation of the study was the lack of analysis of demographic factors or mental aspects and experience due to the limited number of participants. However, it is important to note that mental aspects might be a factor [2, 35], and that age and sex affect energy expenditure [2], with female workers showing higher rates, indicating a higher relative intensity [22]. Consequently, this leads to a higher health-related risk [39]. Furthermore, our study assumed a consistent work pace, which may not be representative throughout an entire workday and is an important factor to consider [29]. Additionally, there is a possibility of measurement bias as the technical error of the device used was reported to be <2% [40]. When interpreting the data, it is important to consider these factors.

Conclusion

In conclusion, this randomised controlled study provides insights into the effects of different work paces on the cardiorespiratory outcomes of industrial workers and assesses their perceived effort and carried load. The results indicate that a higher work pace increases energy expenditure and the cardiorespiratory outcomes $\dot{V}E$, $\dot{V}O_2$, and $\dot{V}CO_2$. However, perceived exertion did not differ significantly across different work paces. Furthermore, the study revealed a substantial impact of work pace on carried load, highlighting potential long-term implications for musculoskeletal health among industrial workers. Nonetheless, the practical relevance of the measured differences still needs to be investigated; the carried load and the higher load with increased work pace should be considered in health-related interventions, along with other factors, such as training status. Taken together, these findings highlight the importance of workplace health promotion in addressing workers' health according to their working conditions. Further research is required to explore the implications of the data on work pace and identify effective interventions. Such efforts will contribute to a better understanding of the complex relationship between workplace and health among industrial workers, ultimately informing more effective interventions to promote occupational health and safety.

List of abbreviations

CL: Carried load; EE: Energy expenditure; HR: Heart rate; MET: Metabolic equivalent; RER: Respiratory exchange ratio; VE: Total ventilation; VCO_2: carbon dioxide release; VO_2: oxygen uptake

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Ethics approval and consent to participate

This study involves human participants, and ethical approval was obtained from the local ethical committee of the University of Wuppertal (SK/AE 240306). Before participating, participants gave informed consent.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and analysed are available from the corresponding author on reasonable quest.

Competing interests

The authors declare that they have no competing interests.

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Authors contributions

SJ is responsible for the overall content as guarantor. SJ was the lead author, contributed to the idea, study design, and data analysis, and wrote the original manuscript. LR contributed to the study design and data analysis. LR, LH, DN, JZ, and JF critically revised the draft and intellectually contributed to it. CB was the study supervisor and contributed to the manuscript critically and intellectually contributed to it. All the authors have read and approved the final version of the manuscript.

References

1. Wang, D., F. Dai, and X. Ning, *Risk Assessment of Work-Related Musculoskeletal Disorders in Construction: State-of-the-Art Review.* Journal of Construction Engineering and Management, 2015. **141**(6): p. 04015008.
2. Dias, M., et al., *Cardiovascular load assessment in the workplace: A systematic review.* International Journal of Industrial Ergonomics, 2023. **96**: p. 103476.
3. Santos, J., et al., *The influence of task design on upper limb muscles fatigue during low-load repetitive work: A systematic review.* International Journal of Industrial Ergonomics, 2016. **52**: p. 78-91.
4. Nur, N.M., et al., *The effects of energy expenditure rate on work productivity performance at different levels of production standard time.* J Phys Ther Sci, 2015. **27**(8): p. 2431-3.
5. Vogel, K., et al., *Increased work pace is unprofitable: a beef-cutting case study.* Meat Sci, 2015. **105**: p. 81-8.
6. Mathiassen, S.E. and J. Winkel, *Physiological comparison of three interventions in light assembly work: reduced work pace, increased break allowance and shortened working days.* Int Arch Occup Environ Health, 1996. **68**(2): p. 94-108.
7. Bosch, T., et al., *The effect of work pace on workload, motor variability and fatigue during simulated light assembly work.* Ergonomics, 2011. **54**(2): p. 154-68.
8. Gooyers, C.E. and J.M. Stevenson, *The impact of an increase in work rate on task demands for a simulated industrial hand tool assembly task.* International Journal of Industrial Ergonomics, 2012. **42**(1): p. 80-89.
9. Januario, L.B., et al., *Can exposure variation be promoted in the shoulder girdle muscles by modifying work pace and inserting pauses during simulated assembly work?* Appl Ergon, 2018. **66**: p. 151-160.
10. Luger, T., et al., *Influence of Work Pace on Upper Extremity Kinematics and Muscle Activity in a Short-Cycle Repetitive Pick-and-Place Task.* Ann Work Expo Health, 2017. **61**(3): p. 356-368.
11. Lee, W., et al., *Physiological responses, trunk posture, and work pace in commercial building cleaning in Washington State: An observational field study.* J Safety Res, 2023. **86**: p. 107-117.
12. Poulianiti, K.P., G. Havenith, and A.D. Flouris, *Metabolic energy cost of workers in agriculture, construction, manufacturing, tourism, and transportation industries.* Ind Health, 2019. **57**(3): p. 283-305.
13. Cancelliere, C., et al., *Are workplace health promotion programs effective at improving presenteeism in workers? A systematic review and best evidence synthesis of the literature.* BMC Public Health, 2011. **11**: p. 395.
14. Weir, J.B., *New methods for calculating metabolic rate with special reference to protein metabolism.* J Physiol, 1949. **109**(1-2): p. 1-9.
15. Jette, M., K. Sidney, and G. Blumchen, *Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity.* Clin Cardiol, 1990. **13**(8): p. 555-65.
16. Foster, C., et al., *A new approach to monitoring exercise training.* J Strength Cond Res, 2001. **15**(1): p. 109-15.
17. Cohen, J., *Statistical power analysis for the behavioral sciences*. 2nd ed. 1988, New York: Lawrence Erlbaum Associates.
18. Brown, J.R. and G.P. Crowden, *Energy Expenditure Ranges and Muscular Work Grades.* Br J Ind Med, 1963. **20**(4): p. 277-83.

19. Li, K.W., et al., *Physiological and perceptual responses in male Chinese workers performing combined manual materials handling tasks.* International Journal of Industrial Ergonomics, 2009. **39**(2): p. 422-427.
20. Biondi, F.N., et al., *Overloaded and at Work: Investigating the Effect of Cognitive Workload on Assembly Task Performance.* Hum Factors, 2021. **63**(5): p. 813-820.
21. Cheng, W.J., et al., *Shift work and physical inactivity: findings from the Finnish Public Sector Study with objective working hour data.* Scand J Work Environ Health, 2020. **46**(3): p. 293-301.
22. Mengelkoch, L.J. and K. Clark, *Comparison of work rates, energy expenditure, and perceived exertion during a 1-h vacuuming task with a backpack vacuum cleaner and an upright vacuum cleaner.* Appl Ergon, 2006. **37**(2): p. 159-65.
23. Ainsworth, B.E., et al., *2011 Compendium of Physical Activities: a second update of codes and MET values.* Med Sci Sports Exerc, 2011. **43**(8): p. 1575-81.
24. Ekblom-Bak, E., et al., *Revisiting the physical activity paradox: the role of cardiorespiratory fitness in workers with high aerobic demands.* Scand J Public Health, 2024. **52**(2): p. 123-127.
25. Imbeau, D., et al., *Oxygen-Consumption during Scaffold Assembling and Disassembling Work - Comparison between Field-Measurements and Estimation from Heart-Rate.* International Journal of Industrial Ergonomics, 1995. **15**(4): p. 247-259.
26. Gilgen-Ammann, R., et al., *Validation of ambulatory monitoring devices to measure energy expenditure and heart rate in a military setting.* Physiol Meas, 2021. **42**(8).
27. Impellizzeri, F.M., et al., *Understanding Training Load as Exposure and Dose.* Sports Med, 2023. **53**(9): p. 1667-1679.
28. Fredriksson, K., et al., *The impact on musculoskeletal disorders of changing physical and psychosocial work environment conditions in the automobile industry.* International Journal of Industrial Ergonomics, 2001. **28**(1): p. 31-45.
29. Jakobsen, M.D., et al., *Is Borg's perceived exertion scale a useful indicator of muscular and cardiovascular load in blue-collar workers with lifting tasks? A cross-sectional workplace study.* Eur J Appl Physiol, 2014. **114**(2): p. 425-34.
30. Christensen, H., et al., *The importance of the work/rest pattern as a risk factor in repetitive monotonous work.* International Journal of Industrial Ergonomics, 2000. **25**(4): p. 367-373.
31. Anagha, R., *A Review on Ergonomic Risk Factors Causing Musculoskeletal Disorders among Construction Workers.* International Journal of Engineering Research and, 2020. **V9**(06).
32. Comper, M.L.C., et al., *Effectiveness of job rotation for preventing work-related musculoskeletal diseases: a cluster randomised controlled trial.* Occup Environ Med, 2017. **74**(8): p. 545-552.
33. Claudon, L., et al., *Temporal leeway: can it help to reduce biomechanical load for older workers performing repetitive light assembly tasks?* Appl Ergon, 2020. **86**: p. 103081.
34. Blaszczyk, A. and M.B. Ogurkowska, *The use of electromyography and kinematic measurements of the lumbar spine during ergonomic intervention among workers of the production line of a foundry.* PeerJ, 2022. **10**: p. e13072.
35. Bezzina, A., et al., *Workplace Psychosocial Factors and Their Association With Musculoskeletal Disorders: A Systematic Review of Longitudinal Studies.* Workplace Health Saf, 2023. **71**(12): p. 578-588.
36. McGonagle, A.K., et al., *Perceived Work Ability: A Constant Comparative Analysis of Workers' Perspectives.* Occup Health Sci, 2022. **6**(2): p. 207-246.

37. Holtermann, A., S.E. Mathiassen, and L. Straker, *Promoting health and physical capacity during productive work: the Goldilocks Principle.* Scand J Work Environ Health, 2019. **45**(1): p. 90-97.

38. Rajeshwari, R., et al., *Do energy expenditure differences across work postures influence cognitive processing speed? A counter-balanced randomised cross-over trial.* Work, 2023. **74**(2): p. 549-563.

39. Campbell, M.K., et al., *Effects of a tailored health promotion program for female blue-collar workers: health works for women.* Prev Med, 2002. **34**(3): p. 313-23.

40. Macfarlane, D.J. and P. Wong, *Validity, reliability and stability of the portable Cortex Metamax 3B gas analysis system.* Eur J Appl Physiol, 2012. **112**(7): p. 2539-47.

Publication 3: Work conditions and determinants of health status among industrial shift workers: A cross-sectional study

Sasha Javanmardi[1], Ludwig Rappelt[1,2], Christian Baumgart[1], Daniel Niederer[3], Lars Heinke[1], Jürgen Freiwald[1]

[1] University of Wuppertal, Department of Movement and Training Science, Wuppertal, Germany

[2] Department of Intervention Research in Exercise Training, German Sport University Cologne, Cologne, Germany

[3] Department of Sports Medicine & Exercise Physiology, Institute of Occupational, Social and Environmental Medicine, Goethe University Frankfurt, Frankfurt/Main, Germany

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Abstract

Introduction: This study investigated potential health status differences among forging, manufacturing, and logistics workers.

Methods: We included 403 participants (age: 41 ± 12 years) from a medium-sized steel company (forge: 64, manufacturing: 299, logistics: 99). Health status was multifactorial assessed: 1) Frequency of musculoskeletal complaints (German Pain Questionnaire). 2) Pain intensity, physical and psychological load (visual analog scales (VAS) 0-100 points). 3) Occupational moderate-to-vigorous physical activity (MVPA), total MVPA, and sedentary behavior (Global Physical Activity Questionnaire (GPAQ)). 4) Quality of life (Short Form Health Survey (SF-36)). Between-group effects were analyzed via one-way ANOVAs with post-hoc Tukey correction.

Results: 308 workers (76.4%) reported at least one musculoskeletal issue. A significant between-group difference was revealed for left shoulder ($F(2,40)= 5.40$; $p= .008$; $\omega^2= .17$), occupational MVPA ($F(2,368)= 9.49$; $p< .001$; $\omega^2= .04$) and total MVPA ($F(2,368)= 6.90$; $p=.001$; $\omega^2=.03$). Post-hoc tests revealed a difference ($p\leq .007$) between manufacturing (left shoulder: n=22; 42.5 ± 24.8; occupational MVPA: n=219; 6978 ± 5137 METs min/week; total MVPA: n=219; 8471 ± 5390 METs min/week) and logistics workers (left shoulder: n=14; 70.4 ± 26.3 au; occupational MVPA: n=96; 9640 ± 4605 METs min/week; total MVPA: n=96; 10856 ± 4680 METs min/week). No other between-group differences were observed.

Discussion: Variations in health disparities across work conditions were observed. Yet, clear distinctions between work conditions and health outcomes remain a challenge. Effective interventions should be focused on job-specific and personalized health profiles rather than a stratification of work conditions to enhance health, productivity, and workforce sustainability.

Keywords

workplace health promotion, occupational health, occupational hazards, musculoskeletal disorders, job-profile

Introduction

Industrial work is recognized as one of the most physically demanding and mentally challenging occupational sectors [1]. Beyond the physical demands, workers are frequently exposed to various occupational hazards, including dust, noise, vibration, awkward postures, repetitive movements, high-force exertion, and high impacts [1-4]. These demands affect workers' health, increasing the risk of illnesses, injuries, and chronic diseases [5, 6]. Among these, work-related musculoskeletal disorders remain a major global concern among industrial workers, characterized by high prevalence rates and a tendency for persistent, long-term complaints despite low incidence ratios [7-9]. For instance, in 2019, more than 50% of manufacturing workers in the EU reported absences due to work-related musculoskeletal disorders, exceeding those caused by flu-related absences [8, 10]. Regarding body zones, the back is the most frequently affected body region, followed by the shoulder/neck, wrist, and knee, underscoring the widespread burden across multiple body regions in this population [7-9].

Addressing these challenges requires a proactive approach to workplace health promotion, which has been shown to enhance worker health and productivity by targeting factors that influence well-being [11, 12]. For instance, the early detection of external factors influencing health status is crucial for timely diagnosis and preventive care, leading to long-term benefits [13]. According to the International Labor Organization (ILO), global trends such as globalization, technological advancements, demographic shifts, and climate change are reshaping the nature of work [14], further emphasizing the importance of workplaces as a platform for promoting healthy habits from a public health perspective to address these challenges [11].

Despite these efforts, standardized health promotion programs often fail to address the complexity of the industrial work environments. Previous research suggests that a one-size-fits-all approach may be too simplistic, and health interventions should consider the diverse working conditions and health disparities within industrial sectors [15-17]. A distinction based on working conditions may be a viable approach for assessing health-related factors. This cross-sectional study aimed to determine whether different working conditions among industrial workers influence health outcomes. These findings intend to guide stakeholders in developing tailored promotion strategies to address the specific needs of the workforce [18].

Material & Methods

Design and ethics

This cross-sectional study investigated industrial workers of a medium-sized steel company in Germany. The local ethics committee approved the study, including all described procedures (SK/AE240527). Before starting data collection, all participants were informed of the study procedure and aim. Then, they voluntarily signed a written informed consent form.

Population and setting

Data collection for this study was conducted between April 2022 and March 2023 by a team of trained research students led by experienced investigators. The team visited the company and screened potentially eligible workers, independent of any company representatives. None of the team members had any personal relationship with the participants.

The inclusion criteria for this study were: (I) age between 18 and 65 years, and (II) current full-time employment as a rotating shift worker in one of three working conditions. Work conditions are physical, environmental, and organizational factors specific to each department, reflecting the cumulative demands and exposure characteristics. The company was stratified into three conditions: forging (high physical and environmental stress, such as heat and noise), manufacturing (moderate physical demands with repetitive tasks), and logistics (dynamic physical activities like lifting and transporting). Participants were excluded if they worked across multiple conditions or were employed as temporary workers.

A total of 1.116 industrial workers were invited to participate in this study. Within the described company's stratum, 206 workers were engaged in forging, 577 in manufacturing, and 333 in logistics.

Procedure

An initial interview was followed by a survey. The procedure encompassed five domains: demographic/anthropometric information, orthopedic complaints, physical activity, quality of life, and assessment of physical and psychological load. Subsequently, all participants provided a paper-and-pencil-based version of the surveys presented in German.

Measurements and outcomes

Pain frequency and intensity

A Part of the German Pain Questionnaire, a validated and reliable tool for assessing musculoskeletal complaints [19], was used to evaluate the location and frequency of orthopedic issues. Participants were presented with a body diagram and instructed to circle any anatomical regions where they experienced pain. The reported pain locations were sorted into the following regions: neck, upper back, right/left shoulder, right/left elbow, right/left wrist, right/left hand, lower back, hip, right/left knee, and foot. Pain frequency was quantified by counting the total number of anatomical regions with reported pain, providing a cumulative measure of musculoskeletal burden for each participant. In addition, pain intensity of each region was graded using a visual analog scale (VAS), ranging from 0 to 10 cm at regular intervals. The VAS is a recognized and reliable tool for measuring pain intensity [20].

Physical activity

The Global Physical Activity Questionnaire (GPAQ) is one of the World Health Organisation's (WHO) stepwise approaches to surveillance of non-communicable disease factors that assess physical activity levels using 16 questions [21]. The questionnaire can calculate the overall physical activity levels by assessing each domain's contribution to overall physical activity [22]. Total moderate-to-vigorous physical activity (MVPA) was calculated for occupational and total day as Metabolic Equivalent (METs) minutes per week. Therefore, when calculating METs using GPAQ data, moderate activity equals 4 METs and 8 METs to the time spent on vigorous activity [23]; additionally, one extra item collected information about the amount of time spent on sedentary behavior [24]. The GPAQ is a suitable and acceptable instrument for monitoring physical activity, and its validity and reliability have been assessed in several countries [24].

Quality of life

The Short Form Health Survey 36 (SF-36) is a questionnaire with 36 items that measure health-related quality of life on eight scales. Principal component analysis revealed two dimensions: The physical dimension represented by the Physical Component Summary (PCS) and the mental dimension represented by the Mental Component Summary (MSC) [25]. The scores ranged from 0 to 100, with 0 being the worst and 100 being the best health status [26]. The German version of the survey is reliable and valid [27].

Physical and psychological load

Subjective physical and psychological loads were assessed using VAS scales, ranging from 0 to 10 cm (0 – 100 points), to evaluate physical and psychological loads, which have proven helpful in research [28]. Participants were asked to rate the perceived demands of their typical workday by answering the following questions: (1) Physical load: "On a typical workday, how physically demanding do you perceive your job to be?"; (2) Psychological load: "On a typical workday, how mentally demanding do you perceive your job to be?"

Data processing and statistical analysis

All data were transferred to an Excel spreadsheet (Microsoft Excel for Mac, Version 16.85, Redmond, WA, USA). Normal distribution was verified using a combination of visual inspection and Shapiro-Wilk tests [29]. Variance homogeneity was visually checked by plotting residuals and using Levene-Test. Potential between-group effects were analyzed via one-way ANOVA with post-hoc Tukey's correction for each outcome. Furthermore, effect sizes using omega square were calculated. The level of significance was set at $p = 0.05$ for all analyses. Statistical analysis was performed with R (version 4.0.3).

Results

Characteristics of the participants are presented in Table 9. A total of 403 participants completed the interview and questionnaires, giving a response rate of 36%. About 67% of the respondents were men, and 33% were women. The majority (31%) of respondents were aged between 30 and 39 years.

Some workers only partially completed the questionnaire; all available data were included in the analysis. 32 participants did not answer the GPAQ, one did not answer the physical and psychological load, and three did not answer the SF-36.

Table 9: Characteristics of the participants

	Age (years)	**Work experience (years)**	**Height (cm)**	**Weight (kg)**	**BMI (kg/m²)**
Total sample (n=411)	41 ± 12	9 ± 9	173.3 ± 9.4	82.3 ± 22.9	27.08 ± 4.57
FO (n=64)	41 ± 11	11 ± 10	176.3 ± 8.0	87.2 ± 14.8	28.00 ± 4.06
MA (n=240)	41 ± 11	9 ± 9	174.6 ± 9.3	81.7 ± 16.3	26.73 ± 4.52
LO (n=99)	42 ± 11	9 ± 10	168.4 ± 8.7	77.7 ± 16.3	27.32 ± 4.92

Mean ± standard deviation; FO = Forge; MA = Manufacturing; LO = Logistics; BMI = body mass index

Pain frequency and intensity

308 workers (76.4%) reported at least one orthopedic issue, compared to 11% reporting at least four problems. The underlying values are presented in Table 10.

Table 10: Orthopedic complaints, BMI, self-reported physical activity, quality of life, physiological and psychological load of the three different working conditions. Furthermore, F-Test p-values (1 x 3 ANOVA) and effect sizes (ω², omega squared) are also provided.

Parameter	Forge	Manufacturing	Logistic	p-value	ω²
Orthopedic Complaints (a.u.)	45 (70%)	181 (75%)	82 (83%)		
BMI (kg/m²)	64 (100%) 28.0 ± 4.06	240 (100%) 26.7 ± 4.52	99 (100%) 27.3 ± 4.92	.119	<.01
Occupational MVPA (METs min/week)	56 (88%) 8462 ± 5757	239 (99%) 6978 ± 5137	99 (100%) 9640 ± 4605*	<.001	.04
Total MVPA (METs min/week)	56 (88%) 9243 ± 5598	239 (99%) 8471 ± 5390	99 (100%) 10856 ± 4680*	.001	.03
Sedentary Behavior (min/day)	56 (88%) 426 ± 152	239 (99%) 439 ± 154	99 (100%) 448 ± 155	.709	<.01
PCS (a.u.)	64 (100%) 47.90 ± 9.46	238 (99%) 46.68 ± 8.53	98 (99%) 45.81 ± 9.28	.34	<.001
MCS (a.u.)	64 (100%) 47.68 ± 9.93	238 (99%) 45.81 ± 10.12	98 (99%) 47.03 ± 10.77	.342	<.001
Physical load (a.u.)	64 (100%) 49.39 ± 28.41	239 (99%) 49.92 ± 24.56	99 (100%) 52.72 ± 27.39	.618	<.01
Psychological load (a.u)	64 (100%) 45.73 ± 29.97	239 (99%) 48.26 ± 29.97	99 (100%) 50.30 ± 29.43	.632	<.01

n (%), mean ± standard deviation, BMI= body mass index (kg/m²), MVPA work = moderate to vigorous work activity per week (METs min/week), MVPA total = moderate-to-vigorous total physical activity per week (METs min/week), PCS = physical component summary, MCS = mental component summary, *significantly higher than manufacturing (p < 0.01).

For pain intensity, only the left shoulder showed a significant effect ($F(2,40)= 5.40$; $p= .008$; $\omega^2= .17$). Post-hoc tests revealed a difference ($p= .007$) between the manufacturing group (n=22; 42.5±24.8 au) and the logistic group (n=14; 70.4±26.3 au), but not between the forge group and any other group. For neck ($F(2,64)= .76$; $p= .472$; $\omega^2= .00$), upper back ($F(2,75)= 1.89$; $p= .158$; $\omega^2= .02$), shoulder right ($F(2,57)= 3.16$; $p= .05$; $\omega^2= .07$), elbow right ($F(2,31)= 3.18$; $p= .055$; $\omega^2= .11$), elbow left ($F(2,3)= 6.58$; $p= .08$; $\omega^2= .65$), wrist right ($F(2,47)= .87$; $p= .426$; $\omega^2= .00$), wrist left ($F(2,32)= 2.35$; $p= .112$; $\omega^2= .07$), low back ($F(2,188)= .98$; $p= .378$; $\omega^2= .00$), knee right ($F(2,42)= 3.18$; $p= .052$; $\omega^2= .09$), knee left ($F(2,32)= 2.70$; $p= .083$; $\omega^2= .09$), foot ($F(2,18)= .82$; $p= .457$; $\omega^2= .00$), no group effect was found. Furthermore, the orthopedic frequencies of the right hand, left hand, and hip were not represented in all groups. Therefore, no further analysis was performed. The values are shown in Figure 8.

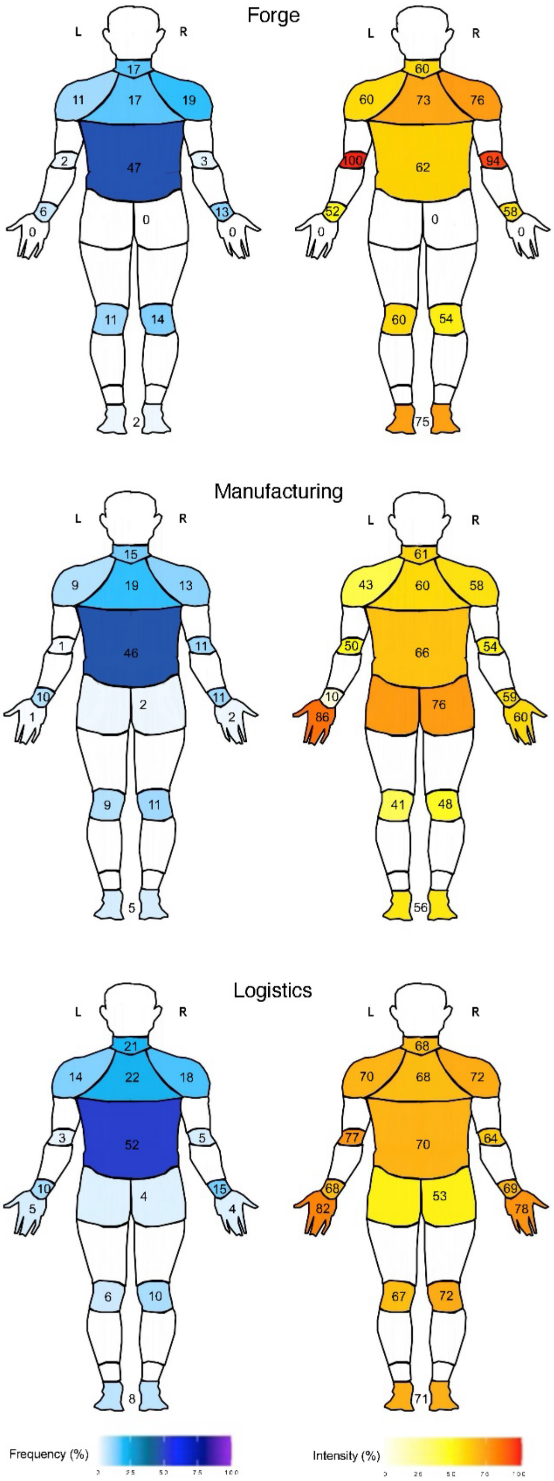

Figure 8: Frequency and pain-intensity of orthopedic complaints of industrial workers in the work conditions forge, manufacturing, and logistics (dorsal view [30])

Physical activity

Occupational MVPA ($F(2,368)= 9.49$; $p< .001$; $\omega^2= .04$) and total MVPA ($F(2,368)= 6.90$; $p=.001$; $\omega^2=.03$) showed a significant between-group difference. Post-hoc testing revealed a significant difference ($p\leq .001$) between the manufacturing group (n=219; 6.978±5.137 METs min/week) and the logistic group (n=96; 9.640±4.605 METs min/week) for occupational MVPA, and between the manufacturing group (n=219; 8.471±5.390 METs min/week) and the logistic group (n=96; 10.856±4.680 METs min/week) for total MVPA. No significant group difference was found for sedentary behavior ($F(2,368)= .34$; $p= .709$; $\omega^2=.00$).

Body composition

No significant group differences were detected in BMI ($F(2,400)= 2.14$; $p= .119$; $\omega^2< .00$).

Quality of life

There were no significant group differences in MCS ($F(2,397)=1.08$; $p= .342$; $\omega^2< .00$) or PCS ($F(2,397)=1.08$; $p= .34$; $\omega^2< .00$).

Perceived load

No significant differences were observed in physical load ($F(2,399)= .48$; $p= .618$; $\omega^2< .00$) or psychological load ($F(2,399) = .46$; $p= .632$; $\omega^2 =.00$).

Discussion

This cross-sectional study aimed to examine whether different industrial work conditions influence the health status of industrial workers. The main findings are (I) a high number of orthopedic complaints with high variability in every group and one significant difference in orthopedic complaints between the manufacturing and logistic conditions; (II) a significant difference between the manufacturing and logistic conditions on physical activity; and (III) no significant differences across all other collected data.

Orthopedic complaints

The literature highlights the significant burden of musculoskeletal disorders in industrial settings [31, 32], driven by various risk factors for their development [8]. Our findings align with this; over 76% of the analyzed workers reported at least one orthopedic issue. This high prevalence reflects similar trends in the literature [7-9] and underscores the critical need for targeted interventions within this population. Research indicates that the interaction of biomechanical and psychosocial risk factors increases the likelihood of developing musculoskeletal disorders [33, 34].

Low back pain emerged as the most frequently reported issue among participants in our study, aligning with prior research [5, 7, 8, 10, 35]. Meta-analyses revealed a mean prevalence between 37% to 51% [7-9], which is consistent with our findings. The strong correlation between workload and the prevalence of low back pain [36, 37] further highlights the need to address these factors through targeted interventions. Additionally, individual factors such as obesity, educational level, and sex have been identified as contributors to a high prevalence of musculoskeletal disorders in the lower back [7].

In addition to the lower back, a systematic review and meta-analysis identified the shoulder, neck, and wrist as the most prevalent sites for musculoskeletal disorders, with a 12-month prevalence ranging from 42% to 60% [8]. Our findings align closely with these observations, highlighting similar patterns of affected body regions. In contrast, another review emphasized that the back, wrist, and elbow are the most common anatomical regions of musculoskeletal disorders [35]. Furthermore, a systematic review and meta-analysis of construction workers identified the lower back, knee, shoulder, and wrist as the most affected body regions [9]. Lower limb musculoskeletal disorders were reported to be less prevalent than back or upper limb, as documented in the literature [7, 8], which aligns with our findings. These variations in the literature reflect the high variability in musculoskeletal disorders, influenced by individual characteristics and work-related factors.

Notably, our study identified significant differences in pain intensity between manufacturing and logistics workers, particularly in the left shoulder. Although the specific cause for this unilateral pain remains unclear, it is plausible that task-specific physical demands or individual biomechanical factors may play a role. Other authors have recognized that there are different tasks and organizations in manufacturing than in logistics, where logistics workers must frequently bend, twist, and stand for a long period of time [38]. Both conditions involve repetitive tasks with low load and high work pace [39], and physically demanding activities such as heavy lifting [39, 40]. These factors are established contributors to musculoskeletal disorders [8, 32].

However, these findings underscore the complexity of addressing musculoskeletal disorders in industrial settings, where workers' tasks and conditions can differ significantly. Therefore, the observed pain in the left shoulder might be attributed to a combination of individual and job-specific factors. The high variability in orthopedic complaints and adverse working conditions pose challenges to the development of generalized interventions. As a result, translating findings into effective solutions requires a focus on tailored strategies that consider individual worker characteristics and specific job demands [41, 42].

Beyond the physical health implications, musculoskeletal disorders affect workability [6, 33], particularly in the low back area [43], prolonged absences [8], and substantial financial costs [40]. They are also one of the leading causes of permanent incapacity [44], productivity loss, and early retirement [11].

Interventions such as ergonomic adaptations and innovative technologies, including robots and exoskeletons [45], might help prevent work-related musculoskeletal disorders by alleviating the physical strain associated with industrial tasks. These approaches are particularly relevant in countries experiencing demographic shifts that challenge the sustainability of physically demanding jobs [3] and human decline in musculoskeletal mass, leading to reduced adaptation strategies [7].

Body composition

A higher prevalence of overweight and obesity among industrial workers than among the general population is known [31]. With a BMI of approximately 27 kg/m^2, our findings fall within the WHO classification of overweight [46]. However, we did not find a significant difference between the conditions, but there was a high variance in the data.

Generally, an increased BMI and musculoskeletal disorders are associated with each other [7], and both negatively impact work-related outcomes [31]. Additionally, obesity is related to musculoskeletal pain [47]. Furthermore, obesity with fat depots is recognized as a significant pro-inflammatory factor in modern society that contributes to modern diseases such as cancer, metabolic disorders, cardiovascular diseases, and dementia [48]. Prevention and, if reasonable, therapy are necessary to improve health and increase healthspan, ideally targeting multiple health factors such as musculoskeletal disorders and obesity [49].

Physical activity

Promoting physical activity in the workplace has been a well-established health strategy for decades [50]. According to prevailing guidelines, optimal physical activity is at least 600 METs min/week [51]. Individuals falling below this WHO recommendations threshold may be classified as physically inactive [22]. In our study, the manufacturing group exhibited the lowest level of occupational MVPA, at 6.978 METs min/week; only four individuals were labeled as physically inactive. However, self-reported data may lead to overestimation of physical activity, particularly in urban areas [52]. In addition, participants appeared to overestimate their MVPA and underestimate their sedentary behavior when using the GPAQ, suggesting that the results should be interpreted with caution [24].

Occupational physical activity exceeds the recommended threshold eleven-fold and can be considered a physical health paradox [53-55]. While the positive association between leisure-time physical activity, orthopedic issues, and cardiovascular disease mortality is well documented [54], occupational physical activity did not have a beneficial association with mortality or orthopedic complaints [54, 55]. On the contrary, high levels of occupational physical activity increase the risk for adverse health outcomes, mortality, and orthopedic complaints [54, 55]. Consequently, promoting decreased physical activity among industrial workers could improve workplace health. While leisure-time physical activity is important for overall health [56], our study found that non-occupational activity accounted for only a modest difference in total physical activity. Given the potential health risks of occupational physical activity, it is essential to consider individual lifestyle factors.

Regarding sedentary behavior, no differences were observed across work conditions, which ranged between 426 and 448 minutes. Despite high physical activity levels, participants sit for over 7.5 hours daily, exceeding the recommended limit for high sedentary behavior [57]. However, sitting for long periods may be a relevant health factor, including posture during sitting from an evolutionary perspective [58].

A notable difference in the manufacturing and logistics groups was observed for both occupational MVPA and total MVPA, with differences of over 660 minutes and approximately 600 minutes, respectively. To contextualize these differences, the WHO recommends at least 150 to 300 minutes of moderate physical activity per week [59]. However, the data showed that job profiles and individual lifestyle factors must be considered when planning and implementing workplace health promotion, especially for those with high physical activity.

Quality of life

Previous research has established a positive correlation between factors such as workability, nutritional intake, and sleep quality on quality of life [60-62]. While these studies highlighted the influence of various factors on quality of life, our study found no significant differences across work conditions. However, our mental and physical scores were lower than those found in other studies with comparable populations [60], and similar to the data from Lim and colleagues [62] for night-shift workers, who comprised most of our participants.

Moreover, our quality of life scores were lower in terms of MCS (50.04) than those of patients with low back pain or disc herniation but higher in PCS (44.51) [63]. Compared to adults in Germany, our results were lower in both categories (MCS: 51.40; PCS:49.30) [64]. Orthopedic complaints could contribute to PCS scores across a range of patients with low back pain to general adults in Germany, but this remains speculative.

Of all participants, 56% had a mental and physical score below 50, which matches the percentage reported by Ghasemi and colleagues [65] (59%). Others have found that one-third of construction workers experience a mental health condition, resulting in high losses in work time and high economic costs [66]. The number of sick days taken due to mental health concerns in the workplace has increased, which is in line with the rising trend of mental illnesses [67, 68]. In particular, shift workers are affected by this trend, with a higher prevalence of poor mental health, particularly depressive symptoms [69, 70]. Workers' exposure to psychosocial hazards is influenced by the interplay between job demands and resources [71], whereas job control may be a possible influencing factor in the manufacturing context [41].

Practical applications

This study offers valuable insights and practical implications for workplace health promotion. Our analysis confirmed the diversity of job profiles among industrial workers. The nature of these job profiles is influenced by factors such as work environment, activities, and human factors [72, 73]. While ergonomic concerns, particularly orthopedic issues, have historically been the focus of workplace health initiatives, our findings underscore the critical need to address psychosocial factors [36]. Unpredictable work hours, for example, hinder workers' access to medical care, contributing to undetected health conditions, poor overall health, and an increased risk of workplace injuries [74]. These challenges negatively affect worker safety and contribute to organizational issues, such as productivity, absenteeism, and rising healthcare costs [14].

Companies strive to meet the increasing expectations of their workers by implementing progressively more comprehensive measures to address these demands [75]. This reinforces the importance of aligning health promotion strategies with specific needs and expectations of the workforce. In this regard, recent reviews highlighted that workplace interventions, particularly in high-risk industries, are associated with a measurable reduction in musculoskeletal disorders [32] and stress-related absenteeism [69]. Studies have demonstrated that health promotion programs reduce the prevalence of physical ailments like low back pain and alleviate mental stress, contributing to a healthier workforce [33, 76]. Besides ergonomics, education is essential and plays a vital role in managing health by equipping workers with skills to adopt a healthier behavior [77].

To address these challenges, practical interventions should adopt a dual approach that combines preventive and rehabilitative strategies tailored to the unique worker and individual and job-specific needs. Strategies such as structured duty schedules, modified working postures, job rotation strategies, and targeted training programs are required to manage workplace health issues effectively [3, 78, 79]. Given the substantial variability in job demands and individual health conditions, frameworks such as the Goldilocks principle [80], which seeks to balance workload demands, and the IGLO framework [81], which targets health promotion at the individual, group, leader, and organizational levels, offer valuable guidance in this regard.

Technological advances can further enhance these strategies. For instance, advanced monitoring technologies, such as wearable devices, allow real-time monitoring of individual health status [82], provide precise data [83], and enable tailored intervention recommendations [84]. Moreover, after identifying specific job profiles and individual health conditions, e-health platforms offer a promising solution for delivering accessible interventions that accommodate irregular work among industrial shift workers [85]. These tools can facilitate personalized health management, improve resource accessibility, and foster proactive health behaviors [86].

Future workplace interventions should systematically integrate these frameworks and technologies to classify health states and develop tailored health-management strategies. For example, task rotation schemes [87] customized with individual psychosocial support [68] can help workers meet their roles' physical and mental demands. The cross-sector applications of such interventions could further validate their effectiveness and adaptability across various industries.

Limitations

Nonetheless, this study had several limitations. A cross-sectional design restricts the ability to infer causality from observed relationships between work conditions and health outcomes. Furthermore, the participants were drawn from a single mid-sized steel company, which restricts the generalizability of our findings to other industrial sectors and broader occupational populations. Potential confounding variables, such as age, sex, and lifestyle habits, were not comprehensively accounted for and may influence the observed relationships. Additionally, the response rate introduces a possible bias that could affect the validity of the findings.

Another notable limitation is the lack of longitudinal data, which prevents the tracking of health outcomes and evaluating their progression. Future research should prioritize longitudinal designs to assess the durability of health improvements and their influence on organizational outcomes. Moreover, the literature has reported a higher prevalence of musculoskeletal disorders in certain body regions when specific tools are used [8]. This highlights the potential variability in reported outcomes based on the methodology employed. Similarly, reliance on self-defined musculoskeletal disorders has been associated with higher incidence rates [7], indicating the need for standardized definitions and assessments in future studies.

In terms of methodology, while we utilized personal interviews to address the inherent challenges of self-reported data, this approach remains subject to recall and reporting bias. Complementing self-reported measures with objective health data or workplace observations in future studies could enhance the reliability of findings.

For broader applicability, systematic reviews comparing interventions across different cultural and regulatory settings could provide valuable insights into a global adaptation of workplace health strategies. Future research should explore how parameters at the individual level, such as physical activity, impact health-related outcomes [56], particularly under more homogenous or task-specific work conditions. This highlights the potential impact of such interventions, particularly in shaping specific job profiles and addressing work-related health issues. Additionally, emphasis should be placed on fostering adequate work conditions within a broader health-related system and ensuring the sustainability and scalability of these approaches.

Conclusion

This study provides valuable insights into working conditions and health status of industrial shift workers. We observed a high prevalence of orthopedic complaints, low quality of life scores, and significant differences in physical activity across work conditions. However, the variability within each work condition suggests that more than stratifying workers based solely on work conditions may be required for effective workplace health interventions. While clear distinctions between work conditions and health outcomes remain challenging, our findings emphasize the importance for a comprehensive approach to workplace health promotion. Successful preventive and rehabilitative programs should focus on an individual level by implementing job-specific profiles and regular health assessments, including adequate screening and monitoring procedures among industrial shift workers. This approach can potentially improve workers' health, enhance productivity, and support a more sustainable workforce.

List of abbreviations

VAS = visual analogue scale; GPAQ = Global physical activity questionnaire; WHO = World Health Organisation; MVPA = moderate-to-vigorous physical activity; MET = Metabolic Equivalent; SF-36 = Short Form Health Survey-36; PCS = physical Component Summary; MCS = Mental Component Summary; BMI = Body Mass Index

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

S.J. and J.F. designed this study, and the data were collected and analyzed by S.J. and L.R. All authors critically examined the results. S.J. had a primary role in preparing the manuscript, which was critically revised by L.R, C.B., D.N., L.H., and J.F. All authors have approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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Data Availability Statement

The datasets used and analyzed are available from the corresponding author on a reasonable quest.

References

1. Ranasinghe, U., et al., *A systematic review on workplace health and safety of ageing construction workers.* Safety Science, 2023. **167**: p. 106276.
2. Xu, X., et al., *Health Monitoring and Management for Manufacturing Workers in Adverse Working Conditions.* J Med Syst, 2016. **40**(10): p. 222.
3. Anagha, R., *A Review on Ergonomic Risk Factors Causing Musculoskeletal Disorders among Construction Workers.* International Journal of Engineering Research and, 2020. **V9**(06).
4. Javanmardi, S., et al., *Impact of work pace on cardiorespiratory outcomes, perceived effort and carried load in industrial workers: a randomised cross-over trial.* Occup Environ Med, 2024. **81**(9): p. 456-461.
5. Abrar, A., et al., *Health status assessment of workers during construction phase of highway rehabilitation projects around lahore, Pakistan.* J Occup Health, 2017. **59**(1): p. 74-80.
6. Nguyen, T.T., et al., *Factors correlated with neuropathic pain among industrial workers in Vietnam: a multi-site cross-sectional study.* Frontiers in Public Health, 2023. **11**.
7. He, X., et al., *Prevalence of work-related musculoskeletal disorders among workers in the automobile manufacturing industry in China: a systematic review and meta-analysis.* BMC Public Health, 2023. **23**(1): p. 2042.
8. Govaerts, R., et al., *Prevalence and incidence of work-related musculoskeletal disorders in secondary industries of 21st century Europe: a systematic review and meta-analysis.* BMC Musculoskelet Disord, 2021. **22**(1): p. 751.
9. Umer, W., et al., *The prevalence of musculoskeletal symptoms in the construction industry: a systematic review and meta-analysis.* Int Arch Occup Environ Health, 2018. **91**(2): p. 125-144.
10. Cimarras-Otal, C., et al., *Adapted exercises versus general exercise recommendations on chronic low back pain in industrial workers: A randomized control pilot study.* Work, 2020. **67**(3): p. 733-740.
11. Andersen, L.L., et al., *Psychosocial effects of workplace physical exercise among workers with chronic pain: Randomized controlled trial.* Medicine (Baltimore), 2017. **96**(1): p. e5709.
12. Moreira-Silva, I., et al., *The effect of a physical activity program on decreasing physical disability indicated by musculoskeletal pain and related symptoms among workers: a pilot study.* Int J Occup Saf Ergon, 2014. **20**(1): p. 55-64.
13. de Walque, D., et al., *Invitations, incentives, and conditions: A randomized evaluation of demand-side interventions for health screenings.* Soc Sci Med, 2022. **296**: p. 114763.
14. Sorensen, G., et al., *The future of research on work, safety, health and wellbeing: A guiding conceptual framework.* Soc Sci Med, 2021. **269**: p. 113593.
15. Aikas, A., et al., *Eight-Year Health Risks Trend Analysis of a Comprehensive Workplace Health Promotion Program.* Int J Environ Res Public Health, 2020. **17**(24).
16. Pega, F., et al., *Monitoring workers' health: focus on rights, determinants, and equity.* Lancet, 2023. **402**(10410): p. 1306-1308.
17. Cui, P., et al., *Modeling the occupational health risk of workers caused by environmental release during the production of PC components.* Frontiers in Public Health, 2022. **10**.

18. Cancelliere, C., et al., *Are workplace health promotion programs effective at improving presenteeism in workers? A systematic review and best evidence synthesis of the literature.* BMC Public Health, 2011. **11**: p. 395.
19. Nagel, B., et al., *[Development and evaluation of the multidimensional German pain questionnaire].* Schmerz, 2002. **16**(4): p. 263-70.
20. Gallagher, E.J., et al., *Reliability and validity of a visual analog scale for acute abdominal pain in the ED.* Am J Emerg Med, 2002. **20**(4): p. 287-90.
21. WHO. *Global physical activity questionnaire (GPAQ)*. 2021 [cited 2024 2024-06-10]; Available from: https://www.who.int/publications/m/item/global-physical-activity-questionnaire.
22. Guthold, R., et al., *Physical activity in 22 African countries: results from the World Health Organization STEPwise approach to chronic disease risk factor surveillance.* Am J Prev Med, 2011. **41**(1): p. 52-60.
23. Chu, A.H., et al., *Reliability and Validity of the Self- and Interviewer-Administered Versions of the Global Physical Activity Questionnaire (GPAQ).* PLoS One, 2015. **10**(9): p. e0136944.
24. Keating, X.D., et al., *Reliability and Concurrent Validity of Global Physical Activity Questionnaire (GPAQ): A Systematic Review.* Int J Environ Res Public Health, 2019. **16**(21).
25. Lins, L. and F.M. Carvalho, *SF-36 total score as a single measure of health-related quality of life: Scoping review.* SAGE Open Med, 2016. **4**: p. 2050312116671725.
26. Barranco-Ruiz, Y., S. Paz-Viteri, and E. Villa-Gonzalez, *Dance Fitness Classes Improve the Health-Related Quality of Life in Sedentary Women.* Int J Environ Res Public Health, 2020. **17**(11).
27. Bullinger, M., *German translation and psychometric testing of the SF-36 Health Survey: preliminary results from the IQOLA Project. International Quality of Life Assessment.* Soc Sci Med, 1995. **41**(10): p. 1359-66.
28. Lesage, F.X. and S. Berjot, *Validity of occupational stress assessment using a visual analogue scale.* Occup Med (Lond), 2011. **61**(6): p. 434-6.
29. Mohd Razali, N. and B. Yap, *Power Comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling Tests.* J. Stat. Model. Analytics, 2011. **2**.
30. Cramer, E., et al., *CHOIRBM: An R package for exploratory data analysis and interactive visualization of pain patient body map data.* PLoS Comput Biol, 2022. **18**(10): p. e1010496.
31. Viester, L., et al., *The effect of a health promotion intervention for construction workers on work-related outcomes: results from a randomized controlled trial.* Int Arch Occup Environ Health, 2015. **88**(6): p. 789-98.
32. Sundstrup, E., et al., *A Systematic Review of Workplace Interventions to Rehabilitate Musculoskeletal Disorders Among Employees with Physical Demanding Work.* J Occup Rehabil, 2020. **30**(4): p. 588-612.
33. Blafoss, R., et al., *Effects of consecutive workdays and days off on low back pain, fatigue and stress: prospective cohort study among warehouse and construction workers.* Occup Environ Med, 2023. **80**(11): p. 650-658.
34. Chaiklieng, S. and P. Suggaravetsiri, *Low Back Pain (LBP) Incidence, Ergonomics Risk and Workers' Characteristics in Relations to LBP in Electronics Assembly Manufacturing.* Indian J Occup Environ Med, 2020. **24**(3): p. 183-187.
35. Wang, D., F. Dai, and X. Ning, *Risk Assessment of Work-Related Musculoskeletal Disorders in Construction: State-of-the-Art Review.* Journal of Construction Engineering and Management, 2015. **141**(6): p. 04015008.

36. Bezzina, A., et al., *Workplace Psychosocial Factors and Their Association With Musculoskeletal Disorders: A Systematic Review of Longitudinal Studies.* Workplace Health Saf, 2023. **71**(12): p. 578-588.
37. Nappo, N., *Is there an association between working conditions and health? An analysis of the Sixth European Working Conditions Survey data.* PLoS One, 2019. **14**(2): p. e0211294.
38. Gajšek, B., et al., *The impact of the applied technology on health and productivity in manual "picker-to-part" systems.* Work, 2020. **65**(3): p. 525-536.
39. Santos, J., et al., *The influence of task design on upper limb muscles fatigue during low-load repetitive work: A systematic review.* International Journal of Industrial Ergonomics, 2016. **52**: p. 78-91.
40. Antwi-Afari, M.F., et al., *Biomechanical analysis of risk factors for work-related musculoskeletal disorders during repetitive lifting task in construction workers.* Automation in Construction, 2017. **83**: p. 41-47.
41. Rosen, P.H. and S. Wischniewski, *Scoping review on job control and occupational health in the manufacturing context.* The International Journal of Advanced Manufacturing Technology, 2019. **102**(5-8): p. 2285-2296.
42. Tersa-Miralles, C., et al., *Effectiveness of workplace exercise interventions in the treatment of musculoskeletal disorders in office workers: a systematic review.* BMJ Open, 2022. **12**(1): p. e054288.
43. Arora, N.K., et al., *The Impact of Exercise Prescription Variables on Intervention Outcomes in Musculoskeletal Pain: An Umbrella Review of Systematic Reviews.* Sports Med, 2024. **54**(3): p. 711-725.
44. Bevan, S., *Economic impact of musculoskeletal disorders (MSDs) on work in Europe.* Best Pract Res Clin Rheumatol, 2015. **29**(3): p. 356-73.
45. Coccia, A., et al., *Biomechanical Effects of Using a Passive Exoskeleton for the Upper Limb in Industrial Manufacturing Activities: A Pilot Study.* Sensors (Basel), 2024. **24**(5).
46. Purnell, J.Q., *Definitions, Classification, and Epidemiology of Obesity*, in *Endotext*, K.R. Feingold, et al., Editors. 2000, MDText.com, Inc.: South Dartmouth (MA).
47. Vincent, H.K., et al., *Musculoskeletal pain, fear avoidance behaviors, and functional decline in obesity: potential interventions to manage pain and maintain function.* Reg Anesth Pain Med, 2013. **38**(6): p. 481-91.
48. Trumble, B.C. and C.E. Finch, *The Exposome in Human Evolution: From Dust to Diesel.* Q Rev Biol, 2019. **94**(4): p. 333-394.
49. Wasser, J.G., et al., *Exercise Benefits for Chronic Low Back Pain in Overweight and Obese Individuals.* PM R, 2017. **9**(2): p. 181-192.
50. Sertel, M., F.D. Üçsular, and Ü. Uğurlu, *The effects of worksite exercises on physical capabilities of workers in an industry of a developing country: A randomized controlled study.* Isokinetics and Exercise Science, 2016. **24**(3): p. 247-255.
51. Sjogaard, G., et al., *The elixir of muscle activity and kinesiology in a health perspective: Evidence of worksite tailored exercise training alleviating muscle disorders.* J Electromyogr Kinesiol, 2021. **61**: p. 102600.
52. Lim, S., et al., *Measurement error of self-reported physical activity levels in New York City: assessment and correction.* Am J Epidemiol, 2015. **181**(9): p. 648-55.
53. Holtermann, A., P. Coenen, and N. Krause, *The Paradoxical Health Effects of Occupational Versus Leisure-Time Physical Activity*, in *Handbook of Socioeconomic Determinants of Occupational Health*, T. Theorell, Editor. 2020, Springer International Publishing: Cham. p. 241-267.
54. Cillekens, B., et al., *Physical activity at work may not be health enhancing. A systematic review with meta-analysis on the association between occupational*

physical activity and cardiovascular disease mortality covering 23 studies with 655 892 participants. Scand J Work Environ Health, 2022. **48**(2): p. 86-98.
55. Coenen, P., et al., *Do highly physically active workers die early? A systematic review with meta-analysis of data from 193 696 participants.* Br J Sports Med, 2018. **52**(20): p. 1320-1326.
56. Amatori, S., et al., *Physical activity, musculoskeletal disorders, burnout, and work engagement: a cross-sectional study on Italian white-collar employees.* Frontiers in Public Health, 2024. **12**.
57. Jelsma, J.G.M., et al., *Time trends between 2002 and 2017 in correlates of self-reported sitting time in European adults.* PLoS One, 2019. **14**(11): p. e0225228.
58. Raichlen, D.A., et al., *Sitting, squatting, and the evolutionary biology of human inactivity.* Proc Natl Acad Sci U S A, 2020. **117**(13): p. 7115-7121.
59. Bull, F.C., et al., *World Health Organization 2020 guidelines on physical activity and sedentary behaviour.* Br J Sports Med, 2020. **54**(24): p. 1451-1462.
60. Tavakoli-Fard, N., et al., *Quality of life, work ability and other important indicators of women's occupational health.* Int J Occup Med Environ Health, 2016. **29**(1): p. 77-84.
61. Manoogian, E.N.C., et al., *Feasibility of time-restricted eating and impacts on cardiometabolic health in 24-h shift workers: The Healthy Heroes randomized control trial.* Cell Metab, 2022. **34**(10): p. 1442-1456 e7.
62. Lim, Y.C., et al., *Association between night-shift work, sleep quality and health-related quality of life: a cross-sectional study among manufacturing workers in a middle-income setting.* BMJ Open, 2020. **10**(9): p. e034455.
63. Morfeld, M., I. Kirchberger, and M. Bullinger, *SF-36 Fragebogen zum Gesundheitszustand: Deutsche Version des Short Form-36 Health Survey*. 2011.
64. Ellert, U. and B.M. Kurth, *[Health related quality of life in adults in Germany: results of the German Health Interview and Examination Survey for Adults (DEGS1)].* Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz, 2013. **56**(5-6): p. 643-9.
65. Ghasemi, S.R., et al., *Sleep Quality and Health-Related Quality of Life in Workers of Kermanshah Industrial Town: A Correlation Study.* Indian J Occup Environ Med, 2020. **24**(2): p. 72-77.
66. Burki, T., *Mental health in the construction industry.* Lancet Psychiatry, 2018. **5**(4): p. 303.
67. Holmlund, L., et al., *Exploring reasons for sick leave due to common mental disorders from the perspective of employees and managers - what has gender got to do with it?* Int J Qual Stud Health Well-being, 2022. **17**(1): p. 2054081.
68. Rakhshani, T., et al., *The relationship between spiritual health, quality of life, stress, anxiety and depression in working women.* Frontiers in Public Health, 2024. **12**.
69. Torquati, L., et al., *Shift Work and Poor Mental Health: A Meta-Analysis of Longitudinal Studies.* Am J Public Health, 2019. **109**(11): p. e13-e20.
70. Yan, T., et al., *Occupational stress and associated risk factors among 13,867 industrial workers in China.* Frontiers in Public Health, 2022. **10**.
71. Amoadu, M., E.W. Ansah, and J.O. Sarfo, *Influence of psychosocial safety climate on occupational health and safety: a scoping review.* BMC Public Health, 2023. **23**(1): p. 1344.
72. de Negreiros, A.W.F.T.R.W., et al., *Manufacturing assembly serial and cells layouts impact on rest breaks and workers' health.* International Journal of Industrial Ergonomics, 2019. **70**: p. 22-27.
73. Katiraee, N., et al., *Consideration of workers' differences in production systems modelling and design: State of the art and directions for future research.* International Journal of Production Research, 2021. **59**(11): p. 3237-3268.

74. Howard, M.E., et al., *Feasibility of cardiovascular risk and sleep health screening in the transport industry.* Journal of Transport & Health, 2020. **18**: p. 100878.
75. Foncubierta-Rodríguez, M.J., M. Poza-Méndez, and M. Holgado-Herrero, *Workplace health promotion programs: The role of compliance with workers' expectations, the reputation and the productivity of the company.* J Safety Res, 2024. **89**: p. 56-63.
76. Kaveh, M.H., et al., *Effectiveness of a transactional model-based education programme for enhancing stress-coping skills in industrial workers: a randomized controlled trial.* Sci Rep, 2023. **13**(1): p. 5076.
77. Schaller, A., et al., *Physical activity interventions in workplace health promotion: objectives, related outcomes, and consideration of the setting—a scoping review of reviews.* Frontiers in Public Health, 2024. **12**.
78. Cheng, S. and Y. Wang, *The impact of perceived environmental competitiveness on employee mental health: a moderated mediation model of job crafting and work–family conflict.* Frontiers in Public Health, 2024. **12**.
79. Wei, W. and L. Li, *The Impact of Artificial Intelligence on the Mental Health of Manufacturing Workers: The Mediating Role of Overtime Work and the Work Environment.* Frontiers in Public Health, 2022. **10**.
80. Straker, L., S.E. Mathiassen, and A. Holtermann, *The 'Goldilocks Principle': designing physical activity at work to be 'just right' for promoting health.* Br J Sports Med, 2018. **52**(13): p. 818-819.
81. Gupta, N., et al., *Effectiveness of a participatory physical and psychosocial intervention to balance the demands and resources of industrial workers: A cluster-randomized controlled trial.* Scand J Work Environ Health, 2018. **44**(1): p. 58-68.
82. Zhang, X., et al., *Manufacturing worker perceptions of using wearable inertial sensors for multiple work shifts.* Appl Ergon, 2022. **98**: p. 103579.
83. Zhang, Y., et al., *Validity of Wrist-Worn photoplethysmography devices to measure heart rate: A systematic review and meta-analysis.* J Sports Sci, 2020. **38**(17): p. 2021-2034.
84. Murray, J.M., et al., *Mobile app for personalized sleep-wake management for shift workers: A user testing trial.* Digit Health, 2023. **9**: p. 20552076231165972.
85. Miguel, C., et al., *Universal, selective and indicated interventions for supporting mental health at the workplace: an umbrella review of meta-analyses.* Occup Environ Med, 2023. **80**(4): p. 225-236.
86. Zahrt, O.H., et al., *Effects of Wearable Fitness Trackers and Activity Adequacy Mindsets on Affect, Behavior, and Health: Longitudinal Randomized Controlled Trial.* J Med Internet Res, 2023. **25**: p. e40529.
87. Padula, R.S., et al., *Job rotation designed to prevent musculoskeletal disorders and control risk in manufacturing industries: A systematic review.* Applied Ergonomics, 2017. **58**: p. 386-397.

General Discussion

The aim of this dissertation was to investigate selected research questions through three studies. The following section discusses the significance of the findings.

Effectiveness of workplace health promotion programs for industrial workers

The first study was a systematic review. It aimed to synthesize evidence on the effectiveness of workplace health promotion interventions among industrial workers, focusing on behavioral, organizational, and safety approaches.

An electronic literature search was conducted through different recommended databases [1, 2]. Included populations were industrial workers aged 18-67 who worked at least 20 hours a week and were active for six months. All workplace interventions carried out during work hours or just before or after were included, along with any passive or active controls and comparisons. The main outcomes of interest were the different dimensions of occupational health and safety [3]. The Cochrane risk-of-bias tool (RoB2) and a modified Down and Black checklist evaluated all included studies [4-6]. A systematic narrative synthesis was conducted because of the varied outcomes and interventions [7].

A total of 39 RCTs were included, including 27 behavioral approaches, 10 multicomponent strategies, 1 organizational, and 1 safety-focused approach.

Most behavioral studies used exercise programs, followed by educational approaches. One study focused exclusively on an organizational approach (job rotation), and only one study addressed safety outcomes. Multi-component interventions combining educational, behavioral, or organizational elements showed inconclusive results.

The findings demonstrated potential for workplace health promotion interventions, but their effectiveness remains unclear. It appears that the population or outcomes assessed in this systematic review may have been overly broad. However, previous reviews that focused on a single parameter [8], specific programs [9], a specific goal like primary prevention [10], or a more narrowly defined scope [11, 12] have reached similar conclusions, which might reflect the complexity of workplace health promotion interventions themselves.

Like earlier systematic reviews, establishing strong recommendations on workplace intervention effectiveness remains challenging [8, 10, 11]. Identifying the most effective intervention types promises is difficult, and due to the high risk of bias in most studies, the evidence remains inconclusive, necessitating cautious interpretation and highlighting the need for further well-designed research [13-15].

Wherever possible, objective measurements should be used to capture parameters accurately. It is essential that the validity of these measurements is ensured [16]. Possible tools include wearable devices [17-21], biomarker analyses [22, 23], or sensors in the workplace to track forces [24] and monitor ergonomics [25, 26]. In the second study of this dissertation, an objective mean value analysis was applied to ensure data collection. In addition, a holistic approach and perspective should be considered, accounting for individuals' natural flexibility, compensation strategies, and adaptations [27]. Furthermore, objective data facilitate effective stratification by identifying worker subgroups with distinct risk profiles and revealing additional factors. This can optimize both interventions' impact and economic viability [28].

A potential approach to addressing this challenge is stratification. Stratification, defined as the grouping of individuals based on their risk of disease or response to therapy, represents a logical and economically viable strategy for workplace health promotion programs [29]. By tailoring interventions to specific worker subgroups, like the IGLOO framework [30], with distinct risk profiles, companies may enhance the effectiveness of workplace health promotion [31]. This concept has been partially implemented in the third study of this dissertation.

Therefore, the first study of this dissertation further provides evidence regarding the different workplace health promotion programs among industrial workers. The synthesis of all studies and the overview may be helpful for practical purposes.

Impact of work pace on cardiorespiratory outcomes, perceived effort and carried load in industrial workers

The second study investigated the effects of various work paces on cardiorespiratory factors, perceived effort, and load carried by industrial workers. We hypothesized that as the work pace increases, so do perceived effort, cardiorespiratory factors, and carried load.

We conducted a randomized crossover design where participants performed repetitive tasks at 100%, 115%, and 130% processing rates.

The findings of the randomized crossover study were as follows: (I) EE, MET, $\dot{V}E$, $\dot{V}O2$, and $\dot{V}CO2$ increase with a higher work pace. (II) RPE did not change with different work paces. (III) The carried load increases with a higher work pace.

(I) The increase in EE, MET, $\dot{V}E$, $\dot{V}O2$, and $\dot{V}CO2$ over time was not unexpected. However, the absolute values observed in this study do not indicate any practical impact on the human body. Unlike in sports contexts, these changes occurred within a range, where the body's inherent flexibility and compensatory mechanisms are sufficient to maintain physiological stability.

(II) The absence of changes in RPE could be attributed to the cardiorespiratory results as well as the limited duration of the work sessions, which may have been insufficient to elicit perceptible effects. Moreover, workers tend to naturally adjust their pace throughout the day, often starting faster and slowing down as the day progresses [32]. Given that the participants were accustomed to a maximum of 130% work pace, which likely influenced their subjective perception of exertion. Notably, strict adherence to a controlled pace led to feelings of discomfort among participants.

(III) The carried load emerged as the most critical factor, as prolonged exposure to higher loads may contribute to musculoskeletal adaptations and long-term orthopedic concerns. Notably, work pace and production process are key factors influencing health risks among industrial workers [33, 34]. This underlines the role of work pace in determining potential acute and chronic issues, characterized by high levels of biomechanical strain [35, 36]. Research demonstrates that work pace varies throughout the day [32], necessitating a dynamic approach to workplace health promotion in addition to profiling. While pre-existing orthopedic conditions were excluded from this study, they are prevalent, as seen in the third study of this dissertation, and must be considered when evaluating tailored and effective treatment. Failure to account for these underlying conditions may lead to an underestimation of the musculoskeletal impact on workers in the long term [37].

These findings underscore the importance of individual variability in workplace health assessments and intervention strategies. Like investors manage risk, workplace health strategies should proactively identify risks, like strain from increased work pace [38]. This approach must weigh potential health risks alongside long-term benefits, such as lower healthcare costs and better productivity, in decision-making [28]. Additionally, it emphasizes that workplace health promotion should be viewed as a continuous and adaptive process that requires continuous monitoring and adaptation. As work pace and load distribution fluctuate depending on worker behavior and material flow, integrating these insights into a human-centered health strategy can enhance worker well-being and mitigate the risks associated with work pace and carried load [39].

Therefore, the second study of this dissertation further contributes to understanding the effects of varying work paces on cardiorespiratory factors, perceived effort, and carried load in industrial workers. Incorporating these findings offers valuable insights for developing dynamic and tailored workplace health promotion strategies to reduce workers' health-related risks and optimizing workers' well-being.

Work conditions and determinants of health status among industrial shift workers

The third study aimed to assess whether varying working conditions among industrial workers affect health outcomes.

403 industrial workers participated in this study, with 64 workers in forging, 299 in manufacturing, and 99 in logistics conditions. A survey followed by an initial interview covered five areas: demographic and anthropometric information, orthopedic complaints, physical activity, quality of life, and the assessment of physical and psychological load.

The key findings are (I) a substantial number of orthopedic issues with considerable variability in each group and one significant difference in orthopedic complaints between the manufacturing and logistics conditions; (II) a notable difference in physical activity between the manufacturing and logistics conditions; and (III) no significant differences across all other collected data.

(I) A substantial number of orthopedic issues were reported across all groups, with notable variability in both the severity and type of complaints. The differences between manufacturing and logistics work may contribute to distinct patterns of musculoskeletal disorders, as specific physical demands in each work condition likely affect orthopedic complaints.

(II) Significant differences in physical activity were observed between the manufacturing and logistics conditions. Workers in logistic conditions reported higher physical activity than manufacturing workers, where more sedentary tasks could be prevalent. However, overall, the physical activity reported by all conditions was notably high, exceeding the recommended levels of physical activity.

(III) No notable differences were found across the other data, which suggests that factors beyond the work conditions, such as individual characteristics or micro-level-work-related factors, may play a more substantial role in influencing these outcomes.

The stratification based solely on working conditions proved to be overly simplistic, as evidenced by the results. While significant differences were found between certain groups, other factors likely contributed to the observed outcomes. Commonly, workplace health promotion programs have focused primarily on behavioral changes [40], as reflected by the number of studies in the first study of this dissertation. However, such programs often neglecting broader contextual factors such as work conditions [41]. It is essential to consider additional factors, such as human factors, including sex and gender-specific needs, physical and psychosocial factors [12, 42], and health hazards [43-46], alongside industrial tasks [47], physical demands [48, 49], leadership [50], shift work [51], and economic factors [52]. These factors can act as potential confounders, adversely affecting worker safety and contributing to organizational issues, such as productivity, absenteeism, and increasing healthcare costs [53].

An example illustrating the oversimplification of stratification in the third study is the results related to low back pain. Current attempts to classify low back pain have not proven effective, likely due to high variability in musculoskeletal disorders driven by individual characteristics and work-related factors. Improving working conditions has been a goal of European policies [54]. Interestingly, its prevalence mirrors similar trends in the general population [55]. However, it remains essential to differentiate between specific and non-specific low back pain [56]. This distinction is crucial for recognizing various compensation strategies and adaptations, which can help in deriving appropriate strategies if possible.

Compensation strategies may help individuals maintain functionality despite exposure to physical demands within the scope of their individual flexibility [27]. However, persistent compensatory strategies can lead to disadvantages, particularly without adequate recovery or adaptation. Over time, these strategies may result in maladaptive changes, contributing to chronic musculoskeletal issues, including low back pain. Chronic health problems are reported by about 20% of employees in the EU, with few stating that these problems impair their daily activities [54].

Chronic low back pain can be referred to as a mismatch condition, where humans are inadequately or insufficiently adapted to modern environmental conditions, a concept derived from natural and cultural selection [57]. Mismatch-diseases are coronary heart disease, hypertension, type 2 diabetes, and more [58]. These mismatch-diseases are not only crucial for workplace health promotion but also for public health at large. However, the current medical approach must be reconsidered, as medicine has reduced mortality rates in the industrial world over the last sixty years, particularly for cardiovascular diseases, but not the case for cancer or type 2 diabetes [59, 60]. Given that these diseases manifest before symptoms appear, the logical conclusion is prevention [61]. Prevention is legally mandated in workplace health promotion, further emphasizing its significance [62].

In addition to preventive approaches, rehabilitative interventions are crucial for workers who have already developed health issues, as highlighted in the results of this study and other reviews [12, 63, 64]. Rehabilitation programs should focus on the associated risks and manage the conditions in the long term [12, 64]. Consequently, systematic assessments within workplace health promotion are necessary to identify affected workers and profiling them to address their specific needs [65]. This highlights the need for effective profiling to develop meaningful stratification approaches and targeted interventions, leading to a holistic approach that integrates preventive and rehabilitative interventions, addressing the natural compensations and adaptations workers undergo. Given the significant variations, methodologies such as the Goldilocks principle and the IGLO framework—focused on health promotion at the individual, group, leadership, and organizational levels—offer valuable insight [66, 67].

All in all, the third study of this dissertation further contributes to understanding the impact of the varying working conditions on health outcomes among industrial workers. By integrating the findings and implications, it provides a foundation for developing targeted and effective workplace health promotion strategies.

Future implications

Future research should explore how workplace health promotion strategies can be optimized both from a health and economic perspective. To achieve meaningful and sustainable impact, such strategies should go beyond general approaches and incorporate specific, context-sensitive interventions. Such interventions should be designed based on the unique demands of industrial setting through effective profiling.

A systems perspective on workplace health promotion emphasizes a holistic approach that considers factors and conditions across multiple levels; the immediate work environment (micro-level), organizational structures and values (meso-level), societal influences (macro-level), and implications for all level such as aging (chrono-level) [68].

To evaluate interventions, both effect and process evaluation are essential. alongside effect evaluations to better understand how and why an intervention is effective or not [40]. While effect evaluation focuses on measurable outcomes such as health improvements or reduced absenteeism, process evaluation offers insight into implementation fidelity, contextual barriers, and worker engagement [69].

Building on this need for specificity and long-term effectiveness, a broader paradigm shift from a sole focus on lifespan toward the prioritization of healthspan could offer a more sustainable approach to promote human well-being [70]. Given the challenges of the German healthcare system [62], integrating healthspan in addition to the natural principle of flexibility, compensation, and adaptation may be essential. Healthspan, defined as the period of life free from disability or chronic disease, is increasingly recognized as a more relevant metric than longevity [71, 72]. However, current medical practices remain predominantly reactive, with limited success in addressing chronic conditions and mismatch diseases [59, 60]. Shifting toward early detection and proactive health management, including continuous health monitoring and systematic assessment, could help bridge the gap, as single intervention suggesting [58]. This aligns with the salutogenic approach, which conceptualizes health as a dynamic process requiring continuous adaptation [73].

A systematic assessment approach can be implemented through monitoring, which can be categorized into two main types: testing procedures and diagnostics and continuous real-time tracking. Traditional testing methods, commonly used in sports science and medicine, assess physical and physiological parameters [74], which are similarly essential in workplace health promotion. Even with a compliance rate as low as 50%, screening strategies involving interventions were still cost-effective in mismatch-diseases [75]. However, these methods frequently fail to capture industrial tasks' dynamic and repetitive nature [76]. This is comparable to the evolution of diagnostics in football, where, over time, effective factors and parameters have been identified and developed into individual player profiles and strategies [77]. As a result, the focus shifted towards real-time data collection [78]. In contrast, the rapid advancement of wearable health technologies has enabled continuous, real-time monitoring, opening new opportunities for early risk detection and timely intervention [79].

The widespread adoption of smart devices offers a more comprehensive understanding of workers' health, workload, and recovery needs [26, 79-82]. Real-time data collection on physical, psychological, and environmental factors [83, 84] provides valuable insights into workers' health and safety [76], and can improve productivity [85, 86]. To be effective, monitoring systems must be adaptable to changing work environments as well as address health disparities [46, 87] and aging [88]. Portable diagnostic devices and biosensors are already used in different environments like space [89]. From this, frameworks can emerge that are flexible and adaptable, allowing for continuous refinement based on evolving work conditions, technological advancements, and specific health needs [90]. This may lead to promoting workplace health initiatives and principles like the Goldilocks principle [91], which can be continuously adapted to optimize interventions based on real-time data in the long term. Furthermore, artificial intelligence could play a crucial role in linking frameworks with profiles and health data [79, 82], enhancing the precision and adaptability of workplace health promotion.

From an industry standpoint, humans should not be simply regarded as a physical compound system, which is the use case in Industry 4.0 [92]. Building on these and previous considerations, the final shift towards Industry 5.0 emphasizes a human-centered approach, which integrates advanced technologies with the inherent compensatory and adaptative capabilities of humans to optimize both productivity and well-being [93]. As industries continuously seek to adapt new technologies for greater efficiency, this human-centered approach has emerged as a pivotal concept shaping the future of industrial systems [79]. In the context of Industry 5.0, the integration of real-time health monitoring systems within industrial environments ensures that human workers remain at the core of technological innovation [94, 95].

Recommendations and practical applications

The following practical implications can be derived from the findings:

- **Tailored workplace health promotion:** Health interventions in industrial settings should be tailored to workers' specific needs and work environments. Behavioral programs, especially exercise interventions, have positively affected musculoskeletal health and mental well-being. However, more research is needed.
- **Workload management and pacing strategies:** Effective workload management that considers carried loads and pacing strategies is critical. Ergonomic measures and workload adjustments are necessary to prevent orthopedic issues and support long-term workplace health promotion.
- **Job-specific health strategies:** Ergonomic adjustments and sector-specific health programs are essential due to varying physical demands in different industrial sectors. Addressing musculoskeletal complaints and promoting healthy behaviors might enhance workforce sustainability and reduce long-term health risks.

Summary and Conclusions

In this dissertation, three studies explored complementary insights into workplace health promotion, emphasizing the complex interactions between health outcomes, work conditions, and individual adaptation.

The first study systematically reviewed workplace health promotion programs, highlighting their potential but also revealing heterogeneous effects across the interventions. The findings underscore the need for more rigorous, stratified research that accounts for population, environmental and organizational factors to optimize intervention strategies.

The second study explored the effects of varying work paces on cardiorespiratory responses, perceived exertion, and carried load. While physiological demands increased with work pace, perceived exertion remained unchanged, suggesting that workers naturally compensate for other workloads over time. However, carried load emerged as a critical risk factor for long-term musculoskeletal concerns. These findings reinforce the importance of adjustments and workload management to mitigate health risks.

The third study examined the impact of work conditions in industrial settings, revealing variations in health outcomes. These results emphasize the need for job-specific, tailored health strategies that address occupational hazards and individual worker characteristics.

Taken together, these studies highlight the dynamic interplay between flexibility, compensation, and adaptation in industrial work environments. They emphasize the necessity of tailored and evidence-based strategies to promote workplace health. Given that workers and their environment constantly evolve, intervention strategies must remain adaptable and responsive to emerging evidence to ensure sustained effectiveness from both a human and technological perspective. A human-centered, stratified approach to workplace health promotion, incorporating continuous monitoring and targeted interventions, can enhance worker well-being and organizational sustainability.

References

1. Lefebvre, C., et al., *Searching for and selecting studies*, in *Cochrane Handbook for Systematic Reviews of Interventions*. 2019. p. 67-107.
2. Bramer, W.M., et al., *Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study.* Systematic Reviews, 2017. **6**(1): p. 245.
3. Burton, J. and W.H. Organization, *WHO healthy workplace framework and model: Background and supporting literature and practices*. 2010: World Health Organization.
4. Sterne, J., et al., *RoB 2: a revised tool for assessing risk of bias in randomised trials.* bmj, 2019. **366**.
5. Eldridge, S., et al., *Revised Cochrane risk of bias tool for randomized trials (RoB 2.0): additional considerations for cluster-randomized trials.* 2016.
6. Hooper, P., et al., *Age-related macular degeneration and low-vision rehabilitation: a systematic review.* Can J Ophthalmol, 2008. **43**(2): p. 180-7.
7. Popay, J., et al., *Guidance on the conduct of narrative synthesis in systematic reviews.* A product from the ESRC methods programme Version, 2006. **1**(1): p. b92.
8. Malik, S.H., H. Blake, and L.S. Suggs, *A systematic review of workplace health promotion interventions for increasing physical activity.* Br J Health Psychol, 2014. **19**(1): p. 149-80.
9. Moreira-Silva, I., et al., *The Effects of Workplace Physical Activity Programs on Musculoskeletal Pain: A Systematic Review and Meta-Analysis.* Workplace Health Saf, 2016. **64**(5): p. 210-22.
10. Goldgruber, J. and D. Ahrens, *Effectiveness of workplace health promotion and primary prevention interventions: a review.* Journal of Public Health, 2009. **18**(1): p. 75-88.
11. Padula, R.S., et al., *Job rotation designed to prevent musculoskeletal disorders and control risk in manufacturing industries: A systematic review.* Applied Ergonomics, 2017. **58**: p. 386-397.
12. Sundstrup, E., et al., *A Systematic Review of Workplace Interventions to Rehabilitate Musculoskeletal Disorders Among Employees with Physical Demanding Work.* J Occup Rehabil, 2020. **30**(4): p. 588-612.
13. Madden, S.K., et al., *The effect of workplace lifestyle programmes on diet, physical activity, and weight-related outcomes for working women: A systematic review using the TIDieR checklist.* Obes Rev, 2020. **21**(10): p. e13027.
14. Amatori, S., et al., *Short High-Intensity Interval Exercise for Workplace-Based Physical Activity Interventions: A Systematic Review on Feasibility and Effectiveness.* Sports Med, 2023. **53**(4): p. 887-901.
15. Brierley, M.L., et al., *The Effectiveness of Sedentary Behaviour Reduction Workplace Interventions on Cardiometabolic Risk Markers: A Systematic Review.* Sports Med, 2019. **49**(11): p. 1739-1767.
16. Zhang, Y., et al., *Validity of Wrist-Worn photoplethysmography devices to measure heart rate: A systematic review and meta-analysis.* J Sports Sci, 2020. **38**(17): p. 2021-2034.
17. Jebelli, H., B. Choi, and S. Lee, *Application of Wearable Biosensors to Construction Sites. I: Assessing Workers' Stress.* Journal of Construction Engineering and Management, 2019. **145**(12): p. 04019079.

18. Erickson, M.L., et al., *Field-Based Assessments of Behavioral Patterns During Shiftwork in Police Academy Trainees Using Wearable Technology.* J Biol Rhythms, 2022. **37**(3): p. 260-271.
19. Gilgen-Ammann, R., et al., *Validation of ambulatory monitoring devices to measure energy expenditure and heart rate in a military setting.* Physiol Meas, 2021. **42**(8).
20. Hickey, B.A., et al., *Smart Devices and Wearable Technologies to Detect and Monitor Mental Health Conditions and Stress: A Systematic Review.* Sensors (Basel), 2021. **21**(10): p. 3461.
21. Zhang, X., et al., *Manufacturing worker perceptions of using wearable inertial sensors for multiple work shifts.* Appl Ergon, 2022. **98**: p. 103579.
22. Bezzina, A., et al., *Workplace Health Promotion Programs Targeting Smoking, Nutrition, Physical Activity, and Obesity in Men: A Systematic Review and Meta-Analysis of Randomized Controlled Trials.* Health Educ Behav, 2024. **51**(1): p. 113-127.
23. Bernardo, T.C., et al., *Physical Exercise and Brain Mitochondrial Fitness: The Possible Role Against Alzheimer's Disease.* Brain Pathol, 2016. **26**(5): p. 648-63.
24. Francés, L., et al., *Design and Development of a Low-Cost Wearable Glove to Track Forces Exerted by Workers in Car Assembly Lines.* Sensors (Basel), 2019. **19**(2).
25. Donisi, L., et al., *Wearable Sensors and Artificial Intelligence for Physical Ergonomics: A Systematic Review of Literature.* Diagnostics (Basel), 2022. **12**(12).
26. Lind, C.M., F. Abtahi, and M. Forsman, *Wearable Motion Capture Devices for the Prevention of Work-Related Musculoskeletal Disorders in Ergonomics-An Overview of Current Applications, Challenges, and Future Opportunities.* Sensors (Basel), 2023. **23**(9).
27. Mulder, T., *Das adaptive Gehirn: über Bewegung, Bewusstsein und Verhalten*. 2007: Georg Thieme Verlag.
28. Lutz, N., et al., *Cost-effectiveness and cost-benefit of worksite health promotion programs in Europe: a systematic review.* Eur J Public Health, 2019. **29**(3): p. 540-546.
29. Erikainen, S. and S. Chan, *Contested futures: envisioning “Personalized,” “Stratified,” and “Precision” medicine.* New Genetics and Society, 2019. **38**(3): p. 308-330.
30. Nielsen, K., et al., *IGLOO: An integrated framework for sustainable return to work in workers with common mental disorders.* Work & Stress, 2018. **32**(4): p. 400-417.
31. Fleckenstein, J., et al., *Individualized Exercise in Chronic Non-Specific Low Back Pain: A Systematic Review with Meta-Analysis on the Effects of Exercise Alone or in Combination with Psychological Interventions on Pain and Disability.* The Journal of Pain, 2022. **23**(11): p. 1856-1873.
32. Mathiassen, S.E. and J. Winkel, *Physiological comparison of three interventions in light assembly work: reduced work pace, increased break allowance and shortened working days.* Int Arch Occup Environ Health, 1996. **68**(2): p. 94-108.
33. Frick, B., U. Götzen, and R. Simmons, *The Hidden Costs of High Performance Work Practices: Evidence from a Large German Steel Company.* ILR Review, 2013. **66**.
34. Jackson, J.A., D. Srinivasan, and S.E. Mathiassen, *Consistent individual motor variability traits demonstrated by females performing a long-cycle assembly task under conditions differing in temporal organisation.* Appl Ergon, 2020. **85**: p. 103046.
35. Bosch, T., et al., *The effect of work pace on workload, motor variability and fatigue during simulated light assembly work.* Ergonomics, 2011. **54**(2): p. 154-68.
36. Claudon, L., et al., *Temporal leeway: can it help to reduce biomechanical load for older workers performing repetitive light assembly tasks?* Appl Ergon, 2020. **86**: p. 103081.

37. Freiwald, J., et al., *Strength training–future directions and misconceptions in rehabilitation after knee injuries–Part 1.* Sports Orthopaedics and Traumatology, 2020.
38. Reid, G.C., N. G Terry, and J.A. Smith, *Risk management in venture capital investor-investee relations.* The European Journal of Finance, 1997. **3**(1): p. 27-47.
39. van Rhijn, J.W., et al., *Finding the Optimal Rhythm in Short Cycle Time Assembly.* IFAC Proceedings Volumes, 2003. **36**(22): p. 65-68.
40. Robroek, S.J., P. Coenen, and K.M. Oude Hengel, *Decades of workplace health promotion research: marginal gains or a bright future ahead.* Scandinavian Journal of Work, Environment & Health, 2021(8): p. 561-564.
41. Carr, L., et al., *Total Worker Health Intervention Increases Activity of Sedentary Workers.* American journal of preventive medicine, 2015. **50**.
42. Bezzina, A., et al., *Workplace Psychosocial Factors and Their Association With Musculoskeletal Disorders: A Systematic Review of Longitudinal Studies.* Workplace Health Saf, 2023. **71**(12): p. 578-588.
43. de Negreiros, A.W.F.T.R.W., et al., *Manufacturing assembly serial and cells layouts impact on rest breaks and workers' health.* International Journal of Industrial Ergonomics, 2019. **70**: p. 22-27.
44. Katiraee, N., et al., *Consideration of workers' differences in production systems modelling and design: State of the art and directions for future research.* International Journal of Production Research, 2021. **59**(11): p. 3237-3268.
45. Guo, H.R., et al., *Prevalence of musculoskeletal disorder among workers in Taiwan: a nationwide study.* J Occup Health, 2004. **46**(1): p. 26-36.
46. Pega, F., et al., *Monitoring workers' health: focus on rights, determinants, and equity.* Lancet, 2023. **402**(10410): p. 1306-1308.
47. Jaffar, N., et al., *A Literature Review of Ergonomics Risk Factors in Construction Industry.* Procedia Engineering, 2011. **20**: p. 89-97.
48. Wang, D., F. Dai, and X. Ning, *Risk Assessment of Work-Related Musculoskeletal Disorders in Construction: State-of-the-Art Review.* Journal of Construction Engineering and Management, 2015. **141**(6): p. 04015008.
49. Dias, M., et al., *Cardiovascular load assessment in the workplace: A systematic review.* International Journal of Industrial Ergonomics, 2023. **96**: p. 103476.
50. Rudolph, C.W., L.D. Murphy, and H. Zacher, *A systematic review and critique of research on "healthy leadership".* Leadership Quarterly, 2020. **31**(1): p. 21.
51. Liu, B.P. and C.X. Jia, *Shift work schedule and sleep patterns in relation to incident depression: Evidence from a prospective cohort study.* Psychiatry Res, 2023. **321**: p. 115076.
52. Rojatz, D., A. Merchant, and M. Nitsch, *Factors influencing workplace health promotion intervention: a qualitative systematic review.* Health Promot Int, 2017. **32**(5): p. 831-839.
53. Sorensen, G., et al., *The future of research on work, safety, health and wellbeing: A guiding conceptual framework.* Soc Sci Med, 2021. **269**: p. 113593.
54. Kubicek, B., et al., *Working conditions and workers' health.* 2019.
55. Fatoye, F., T. Gebrye, and I. Odeyemi, *Real-world incidence and prevalence of low back pain using routinely collected data.* Rheumatology International, 2019. **39**(4): p. 619-626.
56. Freiwald, J., et al., *A Role for Superficial Heat Therapy in the Management of Non-Specific, Mild-to-Moderate Low Back Pain in Current Clinical Practice: A Narrative Review.* Life (Basel), 2021. **11**(8): p. 780.
57. Lieberman, D.E., *Is Exercise Really Medicine? An Evolutionary Perspective.* Curr Sports Med Rep, 2015. **14**(4): p. 313-9.

58. MacDonald, C.S., et al., *Evolutionary Mismatch and Lifestyle-Related Diseases: A Study of a 6-Month Intensive Lifestyle Intervention.* Scandinavian Journal of Medicine & Science in Sports, 2024. **34**(12): p. e14770.
59. Siegel, R.L., et al., *Cancer Statistics, 2021.* CA Cancer J Clin, 2021. **71**(1): p. 7-33.
60. Mensah, G.A., et al., *Decline in Cardiovascular Mortality: Possible Causes and Implications.* Circ Res, 2017. **120**(2): p. 366-380.
61. Attia, P., *Outlive: The science and art of longevity*. 2023: Harmony.
62. Kuhn, K., *Der Betrieb als gesundheitsförderndes Setting: Historische Entwicklung der Betrieblichen Gesundheitsförderung*, in *Lehrbuch Betriebliche Gesundheitsförderung*, G. Faller, Editor. 2017, Hogrefe: Bern. p. 39-56.
63. Umer, W., et al., *The prevalence of musculoskeletal symptoms in the construction industry: a systematic review and meta-analysis.* Int Arch Occup Environ Health, 2018. **91**(2): p. 125-144.
64. Torquati, L., et al., *Shift Work and Poor Mental Health: A Meta-Analysis of Longitudinal Studies.* Am J Public Health, 2019. **109**(11): p. e13-e20.
65. Zhang, Y., et al., *Network analysis of well-being of managerial employees in the construction industry.* Journal of Building Engineering, 2023. **80**: p. 108011.
66. Straker, L., S.E. Mathiassen, and A. Holtermann, *The 'Goldilocks Principle': designing physical activity at work to be 'just right' for promoting health.* Br J Sports Med, 2018. **52**(13): p. 818-819.
67. Gupta, N., et al., *Effectiveness of a participatory physical and psychosocial intervention to balance the demands and resources of industrial workers: A cluster-randomized controlled trial.* Scand J Work Environ Health, 2018. **44**(1): p. 58-68.
68. Skagert, K. and L. Dellve, *Implementing Organizational WHP Into Practice: Obstructing Paradoxes in the Alignment and Distribution of Empowerment.* Front Public Health, 2020. **8**: p. 579197.
69. Proper, K.I. and S.H. van Oostrom, *The effectiveness of workplace health promotion interventions on physical and mental health outcomes - a systematic review of reviews.* Scand J Work Environ Health, 2019. **45**(6): p. 546-559.
70. Lieberman, D.E., et al., *The active grandparent hypothesis: Physical activity and the evolution of extended human healthspans and lifespans.* Proc Natl Acad Sci U S A, 2021. **118**(50).
71. Kaeberlein, M., *How healthy is the healthspan concept?* Geroscience, 2018. **40**(4): p. 361-364.
72. Trumble, B.C. and C.E. Finch, *The Exposome in Human Evolution: From Dust to Diesel.* Q Rev Biol, 2019. **94**(4): p. 333-394.
73. Güllich, A. and M. Krüger, *Grundlagen von Sport und Sportwissenschaft*. 2022: Springer.
74. Hoppe, M.W., et al., *Contrary to endurance, power associated capacities differ between different aged and starting-nonstarting elite junior soccer players.* PLoS One, 2020. **15**(4): p. e0232118.
75. Gillies, C.L., et al., *Different strategies for screening and prevention of type 2 diabetes in adults: cost effectiveness analysis.* Bmj, 2008. **336**(7654): p. 1180-5.
76. Gatti, U.C., S. Schneider, and G.C. Migliaccio, *Physiological condition monitoring of construction workers.* Automation in Construction, 2014. **44**: p. 227-233.
77. Hoppe, M.W., et al., *Physical performance assessment in elite soccer – past, present and future.* 2018. **7**: p. 536-544.
78. Oliva-Lozano, J.M., et al., *Monitoring Elite Soccer Players Physical Performance Using Real-Time Data Generated by Electronic Performance and Tracking Systems.* J Strength Cond Res, 2022. **36**(11): p. 3224-3228.

79. Goh, Y.S., et al., *Machine Learning in Health Promotion and Behavioral Change: Scoping Review.* J Med Internet Res, 2022. **24**(6): p. e35831.
80. Kawada, T., et al., *Monitoring of the sleep patterns of shift workers in the automotive industry.* Work, 2011. **38**(2): p. 163-7.
81. Mach, S., et al., *Assessing mental workload with wearable devices – Reliability and applicability of heart rate and motion measurements.* Applied Ergonomics, 2022. **105**: p. 103855.
82. Donati, M., et al., *ECG-Based Stress Detection and Productivity Factors Monitoring: The Real-Time Production Factory System.* Sensors, 2023. **23**(12): p. 5502.
83. Xu, X., et al., *Health Monitoring and Management for Manufacturing Workers in Adverse Working Conditions.* J Med Syst, 2016. **40**(10): p. 222.
84. Stefana, E., et al., *Wearable Devices for Ergonomics: A Systematic Literature Review.* Sensors (Basel), 2021. **21**(3).
85. Boivin, D.B. and P. Boudreau, *Impacts of shift work on sleep and circadian rhythms.* Pathol Biol (Paris), 2014. **62**(5): p. 292-301.
86. Chen, M.C., et al., *Air Pollution Is Associated with Poor Cognitive Function in Taiwanese Adults.* International Journal of Environmental Research and Public Health, 2021. **18**(1): p. 316.
87. Abuwarda, Z., et al., *Wearable devices: Cross benefits from healthcare to construction.* Automation in Construction, 2022. **142**: p. 104501.
88. Peruzzini, M. and M. Pellicciari, *A framework to design a human-centred adaptive manufacturing system for aging workers.* Advanced Engineering Informatics, 2017. **33**: p. 330-349.
89. Roda, A., et al., *Advanced biosensors for monitoring astronauts' health during long-duration space missions.* Biosens Bioelectron, 2018. **111**: p. 18-26.
90. Stirling, L., Y. Acosta-Sojo, and J.T. Dennerlein, *Defining a systems framework for characterizing physical work demands with wearable sensors.* Ann Work Expo Health, 2024. **68**(5): p. 443-465.
91. Holtermann, A., S.E. Mathiassen, and L. Straker, *Promoting health and physical capacity during productive work: the Goldilocks Principle.* Scand J Work Environ Health, 2019. **45**(1): p. 90-97.
92. Ling, S., et al., *Spatio-temporal synchronisation for human-cyber-physical assembly workstation 4.0 systems.* International Journal of Production Research, 2021. **60**: p. 1-19.
93. Fraga-Lamas, P., J. Varela-Barbeito, and T.M. Fernández-Caramés, *Next Generation Auto-Identification and Traceability Technologies for Industry 5.0: A Methodology and Practical Use Case for the Shipbuilding Industry.* IEEE Access, 2021. **9**: p. 140700-140730.
94. Fraile, F., et al., *A Methodological Framework for Designing Personalised Training Programs to Support Personnel Upskilling in Industry 5.0.* Computers, 2023. **12**(11): p. 224.
95. Jeyaraman, M., A. Nallakumarasamy, and N. Jeyaraman, *Industry 5.0 in Orthopaedics.* Indian J Orthop, 2022. **56**(10): p. 1694-1702.

About the Candidate

Date of birth	26.10.1989 in Remscheid
Home	Bergstr. 40 42651 Solingen

Academic studies

2020 –	Doctoral Studies for Natural Sciences, Department of Movement and Training Science, University of Wuppertal
2017 – 2020	Master of Science in Sport Science (Exercise, Health and Rehabilitation), University of Wuppertal
2010 – 2017	Bachelor of Arts in Sport Science and Philosophie, University of Wuppertal

Career

2024 –	Manager Workplace Health Promotion, KNIPEX-Werk Gustav Putsch KG
2021 – 2024	Scientific Employee, Department of Movement and Training Science, University of Wuppertal
2020 – 2021	Scientific Assistant, Department of Movement and Training Science, University of Wuppertal
2016 – 2020	Student Assistant, Department of Movement and Training Science, University of Wuppertal

Internships

2019	Center for Musculoskeletal Surgery Osnabrück – Klinikum Osnabrück
2018	Workplace health promotion – Bergische Krankenkasse
2014	Carl Fuhlrott Gymnasium

Institutional membership

The European College of Sport Science (ECSS)

Gesellschaft für Orthopädisch-Traumatologische Sportmedizin (GOTS)

Awards

Poster Award (2nd place) – German exercise science & training Conference 2023: Nafisi, S., Mähler, D., Rappelt, L., Heinke, L., Baumgart, C., Freiwald, J., **Javanmardi, S.** (2023). Core exercises and neuromuscular activation: A randomized crossover trial

Paper of highest public interest (3rd place) - Journal of Sports Orthopaedics and Traumatology (SOT): Wagener, S., Hoppe, M. W., Hotfiel, T., Engelhardt, M., **Javanmardi, S.**, Baumgart, C., Freiwald, J. (2020). CrossFit® – Development, Benefits and Risks. Sports Orthopaedics and Traumatology, 36(3), 241-249. Doi

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Publications (peer-review)

Zemke, J., Heinke, L., Rappelt, L., **Javanmardi, S.**, & Baumgart, C. (2025). Akute Effekte exzentrischer und konzentrischer Muskelermüdung auf die neuromuskuläre Leistungsfähigkeit: Eine randomisiert-kontrollierte Cross-Over-Studie. Sports Orthopaedics and Traumatology, 41(2), 168-169. https://doi.org/https://doi.org/10.1016/j.orthtr.2025.02.032

Javanmardi, S., Rappelt, L., Baumgart, C., Niederer, D., Heinke, L., & Freiwald, J. (2025). Work conditions and determinants of health status among industrial shift workers: a cross-sectional study. Frontiers in Public Health, 12. https://doi.org/10.3389/fpubh.2024.1489178

Javanmardi, S., Rappelt, L., Zangenberg, S., Heinke, L., Baumgart, C., Niederer, D., & Freiwald, J. (2025). Effectiveness of workplace health promotion programs for industrial workers: a systematic review. *BMC Public Health*, *25*(1), 168. https://doi.org/10.1186/s12889-025-21365-8

Heinke, L., **Javanmardi, S.**, Rappelt, L., Konrad, A., Schleip, R., Knicker, A. J., Freiwald, J., & Baumgart, C. (2024). Comparison of the effects of cold water immersion and percussive massage on the recovery after exhausting eccentric exercise: A three-armed randomized controlled trial. Front Physiol, 15, 1432009. https://doi.org/10.3389/fphys.2024.1432009

Javanmardi, S., Rappelt, L., Heinke, L., Niederer, D., Zemke, J. A., Freiwald, J., & Baumgart, C. (2024). Impact of work pace on cardiorespiratory outcomes, perceived effort and carried load in industrial workers: a randomised cross-over trial. Occup Environ Med, 81(9), 456-461. https://doi.org/10.1136/oemed-2024-109563

Rappelt, L., **Javanmardi, S.**, Heinke, L., Baumgart, C., Freiwald, J. (2023) The multifaceted nature of recovery after exercise: A need for individualization. Sport Orthop Traumatol, 39(1), 359-367

Freiwald, J., **Javanmardi, S.**, Hotfiel, T., Engelhardt, M., Rappelt, L., Baumgart, C. (2023) Fundamentals of individual loading for strength training after knee injuries. Sport Orthop Traumatol, 39(1), 368-377

Baumgart, C., Heinke, L., **Javanmardi, S.**, Freiwald, J. (2023). Maximal and submaximal isometric strength properties of knee extensors and flexors and their relationship to kinesiophobie and subjective knee function in ACL-recontructed patients. (in preparation)

Freiwald, J., Hoppe, M. W., **Javanmardi, S.**, Hotfiel, T., Engelhardt, M., Grim, C., Baumgart, C. (2023). Monitoring of training and therapy in rehabilitation after patella luxation – A case study.). Sport Orthop Sport Traumatol, 39(1), 28-38.

Javanmardi, S., Baumgart, C., Hoppe, M. W., Freiwald, J. (2022). Sprunghöhenerfassung mittels des Kinexon© Tracking-Systems – eine Pilotstudie. Leipziger Sportwissenschaftliche Beiträge, 63(1), 44-55.

Grim, C., Baumgart, C., Schlarmann, M., Hotfiel, T., **Javanmardi, S.**, Hoffmann, N., Kurz, E., Freiwald, J., Engelhardt, M., Hoppe, M. W. (2022). Effects of Different Orthoses on Neuromuscular Activity of Superficial and Deep Shoulder Muscles during Activities of Daily Living and Physiotherapeutic Exercises in Healthy Participants. Journal of Personalized Medicine, 12(12), 2068.

Freiwald, J., Hoppe, M. W., **Javanmardi, S.**, Hotfiel, T., Engelhardt, M., Grim, C., Baumgart, C. (2020). Current misjudgments and future trends in rehabilitation after knee injuries (Part 1). Sport Orthop Sport Traumatol, 36(3), 250-259.

Wagener, S., Hoppe, M. W., Hotfiel, T., Engelhardt, M., **Javanmardi, S.**, Baumgart, C., Freiwald, J. (2020). CrossFit® – Development, Benefits and Risks. Sports Orthopaedics and Traumatology, 36(3), 241-249.

Freiwald, J., Hoppe, M. W., **Javanmardi, S.**, Hotfiel, T., Engelhardt, M., Grim, C., & Baumgart, C. (2020). Strength training–future directions and misconceptions in rehabilitation after knee injuries–Part 1. Sports Orthopaedics and Traumatology, 36(3), 248-257.

Presentations (published Abstracts)

Klier, K., **Javanmardi, S.** (2025). Schlafend leisten – Systematische Übersicht zu Schlafinterventionen in der industriellen Schichtarbeit. Sports, Medicine, and Health Summit, 26.-28.6.25, Hamburg (Deutschland)

Javanmardi, S., Rappelt, L., Baumgart, C., Niederer, D. (2024) Optimising Health and Productivity in a tailored Intervention for Industrial Workers with Low Back Pain: a stepped wedge cluster randomised controlled trial. Jahrestagung dvs-Kommision Gesundheit, 25.-27.09.2024, Bayreuth (Deutschland)

Klier, K., Hohaus, S., Rappelt, L., Baumgart, C., Niederer, D., **Javanmardi, S.** (2024) Unveiling the Hidden Costs of Shift Work: Sleep, Stress and Activity Patterns in the Industrial Sector. Jahrestagung dvs-Kommision Gesundheit, 25.-27.09.2024, Bayreuth (Deutschland)

Javanmardi, S., Rappelt, L., Heinke, L., Freiwald, J., Baumgart, C. (2023). The impact of different work paces on energy demand in industrial workers: A randomized controlled trial. Jahrestagung dvs-Sektion Trainingswissenschaft, 9.-10.11.23, Köln (Deutschland)

Heinke, L., **Javanmardi, S.**, Rappelt, L., Konrad, A., Schleip, R., Knicker, A., Baumgart, C., Freiwald, J.(2023, 04.-07.07.). Comparison of the effects of cold-water immerson and percussive massage on the recovery after exhausting eccentric exersise: A three-armed randomized control trial. 28th Annual Congress of the European College of Sport Science (ECSS), Paris (France).

Freiwald, J., **Javanmardi, S.**, Baumgart, C. (2023). Sportverletzungen - von der Propriozeption zur neuromuskulären Ansteuerung. 38. Jahrestagung der Gesellschaft für Orthopädisch-Traumatologische Sportmedizin (GOTS), 15.-17.06., Luxemburg (Luxemburg).

Javanmardi, S., Rappelt, L., Baumgart, C., Heinke, L., Freiwald, J. (2023). Lokalisation, Häufigkeit und Schmerzintensität orthopädischer Beschwerden bei Industriearbeitern – Können wir aus dem Leistungssport lernen? 38. Jahrestagung der Gesellschaft für Orthopädisch-Traumatologische Sportmedizin (GOTS), 15.- 17.06., Luxemburg (Luxemburg).

Abstracts (peer review)

Javanmardi, S., Rappelt, L., Heinke, L., Freiwald, J., Niederer, D., Baumgart, C. (2024). The influence of work pace on energy expenditure and load in industrial workers: A randomized crossover trial. 29th Annual Congress of the European College of Sport Science (ECSS), Glasgow (Scottland)

Nafisi, S., Mähler, D., Rappelt, L., Heinke, L., Baumgart, C., Freiwald, J., **Javanmardi, S.** (2023). Core exercises and neuromuscular activation: A randomized crossover trial. German exercise science & training Conference 2023. Deutsche Vereinigung für Sportwissenschaft (dvs), Cologne (Germany)

Baumgart, C., Grim, C., Heinke, L., **Javanmardi, S.**, Rappelt, L., Freiwald, J., Hoppe, M. W. (2023). Compensation strategies after a complete avulsion of the proximal rectus femoris

muscle: A single case one-year follow-up. 28th Annual Congress of the European College of Sport Science (ECSS), Paris (France).

Javanmardi, S., Rappelt, L., Heinke, L., Baumgart, C., Freiwald, J. (2023). Health status assessment of industrial workers in a mid-size company: A novel approach in workplace health promotion. 28th Annual Congress of the European College of Sport Science (ECSS), Paris (France).

Schlotter, M., Terhorst, S., Baumgart, C., Rappelt, L., **Javanmardi, S.**, Freiwald, J., Heinke, L. (2023). Einfluss perkussiver Massage auf den Muskeldehnungsreflex bei 15 plötzlicher Supination des Fußes. 38. Jahrestagung der Gesellschaft für Orthopädisch-Traumatologische Sportmedizin (GOTS), 15.-17.06., Luxemburg (Luxemburg).

Javanmardi, S., Rappelt, L., Baumgart, C., Heinke, L., Freiwald, J. (2023). Lokalisation, Häufigkeit und Schmerzintensität orthopädischer Beschwerden bei Industriearbeitern – Können wir aus dem Leistungssport lernen? 38. Jahrestagung der Gesellschaft für Orthopädisch-Traumatologische Sportmedizin (GOTS), 15.- 17.06., Luxemburg (Luxemburg).

Javanmardi, S., Baumgart, C., Heinke, L., Grim, C., Engelhardt, M., Freiwald, J. (2022). Kasuistik nach traumatischer Patellaluxation mit MPFL-Plastik Versorgung - Funktionsdiagnostische Befunde. 37. Jahrestagung der Gesellschaft für Orthopädisch-Traumatologische Sportmedizin (GOTS), 19.-20.05., Berlin.

Hoppe, M.W., Hotfiel, T., Baumgart, C., **Javanmardi, S.**, Kurz, E., Freiwald, J., Engelhardt, M., Grim, C. (2021). Einfluss verschiedener Orthesen auf die neuromuskuläre Aktivierung oberflächiger und tiefer Schultermuskeln während Alltagsbewegungen und Eigenübungen. 36. Jahreskongress der Gesellschaft für Orthopädisch-Traumatologische Sportmedizin (GOTS), 01.06, Basel.

Javanmardi, S., Brochhagen, J., Baumgart, C., Hoppe, M.W., Freiwald, J. (2020). Impact of pre-season preparation on intermittent endurance performance in top-level handball. 2. Fitness-Wissenschaftskongress, 28.-29.02, Düsseldorf.

Teaching courses and evaluation

Semester	Course	Presentation material	Structure	Support	Presentation / discussion	Overall evaluation
WS20/21	Leistungsdiagnostik und Training in ausgewählten Spielsportarten	1.3	1.5	1.1	1.4	1.2
SS21	Leistungsdiagnostik und Training in ausgewählten Spielsportarten	Not applicable				
SS22	Betriebliches Gesundheitsmanagement	1.1	1.1	1.0	1.2	1.0
SS23	Exercise and Health	1.2	1.2	1.1	1.3	1.2
SS23	(Lecture) Bewegung und Gesundheit	Not applicable				

1 = maximal value; 5 = minimal value

Supervised empirical studies

Nafisi, S. (2025). Effekt von Exercise Snacks auf Gesundheitsparameter bei Bürokräften. Eine randomisierte kontrollierte Studie. Master-Thesis. University of Wuppertal

Langemeyer, N. (2024). Gesundheitsstatus der Schichtarbeiter bei Lidl Deutschland. Bachelor-Thesis. University of Wuppertal

Scheuten, L. (2024). Mögliche Unterschiede in der Gesundheit von Lehrkräften an Grundschulen und Gymnasien. Bachelor-Thesis. University of Wuppertal.

Ecke, C. (2023). Comparison of ergonomic recommendations, low back pain and spine shape in office workers. Bachelor-Thesis. University of Wuppertal

Weber, A. (2023). Evaluation von krafttrainingsbezogenen Beiträgen bei Fitnessinfluencer – eine qualitative Analyse. Bachelor-Thesis. University of Wuppertal

Koziol, J. (2023). Wie verhält sich die körperliche Aktivität während der Arbeit, auf dem Arbeitsweg und in der Freizeit zwischen männlichen und weiblichen Industrieangestellten. Bachelor-Thesis. University of Wuppertal

Hohaus, S. (2023). Körperliche Aktivität und Schlafverhalten von Industriearbeitern. Master-Thesis. University of Wuppertal

Beckmann, H. (2023). Bewertung der körperlichen Aktivität von Industriearbeitern in verschiedenen Schichten und Abteilungen mithilfe von Garmin Vivosmart 4 Smartwatches. Bachelor-Thesis. University of Wuppertal

Hein, A. K. (2022). Vergleich der gesundheitsbezogenen Lebensqualität von Schichtarbeitenden zweier Produktionsabteilungen anhand des SF-36 Health-Surveys. Bachelor-Thesis. University of Wuppertal.

Bachmann, A. L. (2022). Die Relevanz der Erhebung persönlichkeitsbezogener Merkmale anhand der BIG Five bei Schicharbeitern in Hinblick auf betriebliche Gesundheitsmaßnahmen. Bachelor-Thesis. University of Wuppertal.

Schöttler, L. W. (2022). Explorative Studie zu repetitiven Bewegungen an einem Arbeitsplatz in der industriellen Produktion mittels EMG. Bachelor-Thesis. University of Wuppertal.

Zangenberg, S. (2022). Wirksamkeit von gesundheitsfördernden Interventionen bei körperlich tätigen Arbeitskräften. Master-Thesis. University of Wuppertal

Schusdzarra, P. (2021). Subjektive und objektive Messmethoden bei Bauchmuskelübungen. Eine EMG-basierte Studie im Vergleich zur subjektiven Empfindung der Übungsintensitäten. Bachelor-Thesis. University of Wuppertal.

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