

Worker Behaviour and Personal Protective Equipment Effectiveness: A Bibliometric Analysis

Saina Omar*, Irman Abdul Rahman & Syazwani Mohd Fadzil

Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor.

**Corresponding author: p102905@siswa.ukm.edu.my*

Received 18 February 2026, Received in revised form 3 June 2026

Accepted 3 July 2026, Available online 30 September 2026

ABSTRACT

Personal protective equipment (PPE) is a fundamental component of occupational health and safety; however, its effectiveness is strongly influenced by worker behaviour, organisational context, and human factors. Despite the long-standing use of PPE, research in this field remains fragmented and rapidly expanding, making it difficult to develop a comprehensive understanding of how worker behaviour influences PPE effectiveness over time. This bibliometric review addresses this gap by systematically analysing scientific publications from 1970 to 2026 to identify publication trends, influential studies, leading contributing countries, dominant research themes, and patterns of international collaboration. Data were retrieved from Scopus and Web of Science, resulting in a final dataset of 1,236 peer-reviewed journal articles. Scopus Analyzer, OpenRefine, and VOSviewer were employed for descriptive, bibliometric, and network analyses. The findings reveal a prolonged formative phase followed by substantial publication growth after 2019, largely driven by increasing global attention to occupational safety and the COVID-19 pandemic. Research output remains concentrated in several high-income countries, while contributions from developing regions remain limited. Keyword analysis demonstrates a shift from technical PPE performance to behavioural dimensions, including compliance, risk perception, safety culture, usability, and organisational influence. International collaboration networks reveal major research hubs and global disparities in research integration. Overall, this study highlights the increasing importance of behavioural and socio-technical perspectives in PPE research and provides a foundation for future interdisciplinary studies, evidence-based safety policies, workplace intervention strategies, and sustainable occupational health practices aimed at improving long-term worker safety outcomes.

Keywords: Personal protective equipment; worker behaviour; occupational, safety; health

INTRODUCTION

Personal protective equipment (PPE) is a key aspect of occupational health and safety, serving as a primary defence between employees and various occupational hazards. However, regardless of technological advancement and regulatory recommendations, the effectiveness of PPE in preventing occupational injuries and diseases does not depend solely on its design or material characteristics. There is a growing body of literature on the importance of worker behaviour in the real-life protective performance of PPE. Factors such as knowledge, attitudes, risk perception, and organisational safety culture interact in complex ways that influence how PPE is worn, maintained, and integrated into daily work activities. This perspective

has gradually transformed the occupational safety research paradigm from a technical, control-oriented approach to a more holistic one that includes behavioural and psychosocial factors (Ayu et al. 2018; Kibirige et al. 2024; Santos et al. 2025; Yaghoti et al. 2021).

The persistence of poor PPE adherence, even in high-risk workplaces, highlights the importance of understanding the behavioural determinants of PPE use. Empirical evidence shows that leadership style, safety climate, peer influence, and feelings of comfort and fit significantly affect the consistency and accuracy of PPE use. Furthermore, the gap between the theoretical protection offered by PPE and its practical implementation is often linked to a lack of compliance, improper use, and design constraints that do not account for user diversity. This review seeks to clarify

the complex relationship between worker behaviour and PPE use by integrating empirical data and theoretical perspectives to establish a basis for targeted interventions and future research directions (Ayu et al. 2018; Kibirige et al. 2024; Santos et al. 2025; Yaghoti et al. 2021).

LITERATURE REVIEW

The factors affecting workers' compliance with the use of PPE have been widely studied, and the results indicate an interaction of individual, organisational, and situational factors. Knowledge and supervisory practices of workers are consistently reported as crucial predictors of PPE compliance, and it has been shown that a lack of training and lax enforcement contribute to non-compliant behaviour (Ayu et al. 2018; Kibirige et al. 2024). Specifically, transformational and transactional leadership approaches have been shown to positively influence motivation and foster a more safety-oriented culture, while a robust safety management system and a supportive social environment further encourage the use of PPE (Akbarzadeh et al. 2025; Khoshakhlagh et al. 2024; Ratu et al. 2019). Age and gender have also been identified as individual traits influencing compliance patterns, with female and older workers tending to exhibit higher rates of compliance. Nonetheless, they are usually influenced by the broader workplace culture and the availability of well-fitting and comfortable equipment (Bentum et al. 2022; Kibirige et al. 2024). Widely reported barriers to the use of PPE, such as discomfort, poor fit, thermal burden, and perceived interference with work activities, highlight the importance of ergonomics and user-centred design in the selection and application of PPE (Lombardi et al. 2009; Sharma et al. 2022).

Field-based testing across various industries indicates a consistent gap between the theoretical performance of PPE tested in the laboratory and its actual performance in real working environments. Studies conducted in healthcare, manufacturing, and construction contexts show that the protective benefits achieved in practice are often less than those claimed by manufacturers. Much of this is attributed to the poor fit, discomfort, and inconsistent usage. Prolong use of PPE, especially in healthcare settings, has been associated with negative physical and cognitive effects, such as skin problems, headaches, fatigue, and communication difficulties, which can also contribute to reduced compliance and performance of duties (Brisbine et al. 2022; Bukhtiyarov et al. 2023). Meta-analytical research indicates that PPE use is associated with some of the lowest injury risks; however, only about half of workers reportedly wear it consistently, with lack of availability,

lack of training, and time cited as the most common factors (Santos et al. 2025). In general, these findings indicate the need to develop more robust evaluation procedures, more efficient training methods, and design enhancements to optimise protective efficacy and usability. This aligns with previous studies that highlight limitations in traditional training evaluation models, particularly in capturing complex and real-world outcomes (Giangreco et al. 2010; Kirwan 2025). Furthermore, earlier research on PPE effectiveness emphasises the importance of usability, training, and real-world application in determining protective performance (Mayer & Korhonen 1999). Recent studies have also highlighted the increasing influence of behavioural compliance, safety awareness, ergonomic suitability, and workplace training in improving PPE effectiveness across occupational settings (Hoernke et al. 2021; Khorsandi et al. 2025; Ong et al. 2020; Tabah et al. 2020).

Behavioural frameworks have helped to understand the mechanisms that influence PPE-related behaviour and to make inferences about how to develop interventions. Social cognitive theory (SCT), health belief model (HBM), and the capability, opportunity, motivation-behaviour (COM-B) framework have been extensively used to explain and predict PPE compliance, focusing on the roles of self-efficacy, perceived susceptibility, and supportive environmental factors (Seah et al. 2025; Tessema & Sema 2022; Yaghoti et al. 2021). The theoretical domains framework (TDF) and the behaviour change wheel have been particularly useful for systematically identifying behavioural barriers and their links to specific intervention strategies, including leadership communication, environmental change, and peer role modelling (Curtis et al. 2022; Olson et al. 2009). It is also acknowledged that social learning processes and normative pressures are particularly strong in maintaining PPE use, and empirical data show that compliance improves when workers observe other workers and supervisors consistently using PPE correctly (Lu et al. 2015; Olson et al. 2009). These observations support the concept of multi-level interventions focused simultaneously on individual beliefs, social interactions, and organisational systems. Recent studies also emphasise that behavioural compliance and sustained PPE use are strongly influenced by organisational safety culture, peer behaviour, and continuous workplace supervision, particularly in high-risk occupational environments (Kibirige et al. 2024; Seah et al. 2025).

Despite these developments, significant knowledge gaps remain regarding the behavioural aspects of PPE effectiveness. There is some evidence of compensatory risk-taking behaviour, where people take riskier actions while wearing protective equipment, but this is not well understood, particularly regarding the roles of personality

traits and work context (Braun & Fouts 1998; DellaValle et al. 2012). Moreover, the physical and psychological effects of prolonged PPE use, such as ergonomic stress and impacts on mental health, have not been thoroughly examined. Small and medium-sized enterprises (SMEs) face unique challenges, including less developed regulatory control and formal safety training, which are also not reflected in the literature (Akbarzadeh et al. 2025; Lee et al. 2021). An even greater limitation to the external validity of the current studies is methodological constraints, including a heavy reliance on self-reported compliance measures and the absence of an external test of real-world performance (Bentum et al. 2022; Denisov et al. 2013). To address these gaps, interdisciplinary interventions combining behavioural science, ergonomics, and organisational policy, along with the development of adaptive PPE solutions and real-time feedback systems, will be necessary to support sustained compliance and worker well-being (Lee et al. 2021). Recent studies have highlighted the increasing importance of adaptive safety systems, ergonomic interventions, and integrated workplace monitoring in improving long-term PPE compliance and occupational well-being (Khoshakhlagh et al. 2024; Seah et al. 2025).

Overall, the literature consistently demonstrates that worker behaviour plays a decisive role in determining the real-world protective value of PPE. Although advancements in PPE technology remain essential, they are insufficient without concurrent efforts to address behavioural, organisational, and contextual influences on compliance.

The application of behavioural theory to intervention design, supported by empirical assessments of safety outcomes and user experience, offers a viable approach to enhancing occupational safety performance. However, persistent research gaps, particularly regarding compensatory behaviours, prolonged PPE use, and the concerns of diverse workforce groups, highlight the need for ongoing targeted research and innovation in this important area of occupational health studies.

RESEARCH QUESTIONS

RQ1. What are the temporal publication trends in research on worker behaviour and PPE effectiveness over time?

RQ2. Which publications are the most influential in this research domain based on citation analysis?

RQ3. Which countries are the leading contributors to the literature on worker behaviour and PPE effectiveness in terms of publication output and citation impact?

RQ4. What are the most frequently occurring and thematically significant keywords, and how do they reflect the intellectual structure of research on worker behaviour and PPE effectiveness?

RQ5. What are the patterns of international co-authorship and collaboration among countries in research on worker behaviour and PPE effectiveness?

METHODOLOGY

Bibliometric analysis involves the structured acquisition, classification, and evaluation of bibliographic information from scholarly publications (Al-Khoury et al. 2022; Alves et al. 2021; Assyakur & Rosa 2022). Beyond conventional descriptive measures, such as sources of publication, annual output patterns, and leading contributors, Wu and Wu (2017) noted that bibliometric methods also include more advanced techniques, such as document co-citation analysis, to demonstrate intellectual connections within the literature. A rigorous bibliometric review is a complex and systematic process, involving the careful formulation of search terms, thorough database searches, and meticulous data processing. This methodological rigour supports the development of a comprehensive bibliographical dataset and ensures the reliability and repeatability of research findings (Fahimnia et al. 2015).

Following this strategy, the current research included high-impact academic literature, as these publications are important sources of critical information on the theoretical foundations and knowledge framework of the research area of interest. The Scopus database was selected as the primary source for literature retrieval to ensure accuracy and consistency of data (Al-Khoury et al. 2022; Di Stefano et al. 2010; Khiste & Paithankar 2017). To maintain academic excellence, only peer-reviewed journal articles were analysed, excluding books and instructional materials (Gu et al. 2019). Using the Scopus platform from Elsevier, which provides multidisciplinary coverage, relevant publications from 1970 to 2026 were systematically collected and subsequently subjected to bibliometric analysis.

The Scopus database was selected as the primary data source because of its extensive historical coverage and comprehensive indexing across multiple disciplines, enabling long-term analysis from 1970 to 2026. This extended timeframe enables the identification of

longitudinal trends and the evolution of research on worker behaviour and PPE effectiveness. In addition, Web of Science was included as a supplementary database to enhance data robustness and reduce potential database bias. The inclusion of Web of Science aimed to capture recent research developments and validate publication trends identified in the Scopus dataset. This approach ensures both historical depth and contemporary relevance in the analysis.

The data retrieval process was conducted in April 2026 using the Scopus and Web of Science databases. Retrieved records were exported in plaintext format and screened according to predefined inclusion and exclusion criteria. The inclusion criteria comprised peer-reviewed journal articles published in English within the selected subject areas: medical, engineering, social science, environmental science, and public environmental occupational safety and health. Non-English publications, books, conference papers, editorials, and publications outside the selected subject areas were excluded. The bibliographic records were then cleaned, standardised, and harmonised using OpenRefine before being analysed with Scopus Analyzer and VOSviewer.

DATA SEARCH STRATEGY

A total of 4,049 peer-reviewed journal articles were retrieved from the Scopus database using the search string presented in Table 1: TITLE-ABS-KEY ((worker* OR "workforce" OR "employee" OR "staff" OR "labour") AND (behaviour* OR "behavioural" OR "conduct" OR "actions" OR "practices") AND ("personal protective equipment" OR PPE OR "safety gear" OR "protective gear" OR "safety equipment")). The retrieved publications covered multiple disciplinary domains, including environmental sciences, social sciences, engineering, and medical sciences, reflecting the interdisciplinary and evolving nature of research on worker behaviour and the effectiveness of personal protective equipment (PPE) from 1970 to 2026.

In addition, a supplementary search was conducted using the Web of Science database to enhance the robustness of the data collection process and minimise potential database bias. Consistent filtering criteria, including document type, subject category, and language, were applied during the search process, resulting in 135,654 relevant records. However, most of these records were excluded during the screening and eligibility stages because

the broad multidisciplinary indexing of Web of Science included many studies beyond the specific behavioural and PPE-related scope of this study. Differences in the number of records retrieved compared to Scopus may be due to variations in database indexing coverage and search structures. The greater number of records retrieved from Web of Science may result from its broader multidisciplinary indexing and wider keyword coverage. Nevertheless, Scopus was retained as the primary database because of its extensive historical coverage, multidisciplinary indexing, and suitability for long-term bibliometric trend analysis. Web of Science was therefore used as a complementary database to enhance data robustness and validate the consistency of the findings.

The temporal distribution of publications indicates a gradual development of scholarly interest in PPE-related behavioural issues during the early decades, followed by a marked increase from the late 1990s onwards. This expansion can be attributed to increasing global attention to occupational health and safety, the development of regulatory frameworks, and the recognition that technical measures alone are insufficient to prevent workplace injuries. The most significant increase in publication output, especially since 2020, is likely driven by global health crises such as the COVID-19 pandemic, which intensified research on PPE usage, compliance, and human factors in both healthcare and non-healthcare settings.

The thematic framework of the literature, based on keyword constraints such as PPE, human, accident prevention, workplace, and attitude to health, demonstrates a clear evolution in research focus, as shown in Table 1. Table 1 also outlines the structured search strategy and keyword selection, highlighting how both technical and behavioural dimensions of PPE research are systematically captured. Earlier studies primarily focused on hazard control and equipment performance, while more recent research increasingly emphasises behavioural perspectives. This shift highlights the increasing importance of worker knowledge, risk perception, attitudes, and organisational safety culture as key determinants of PPE effectiveness.

The dominance of behavioural and psychosocial keywords indicates that PPE effectiveness in real-world settings is strongly mediated by human decision-making and the social environment, rather than solely dependent on technical specifications. This observation reinforces the importance of integrating behavioural and organisational factors with technical measures to improve the effectiveness of PPE, particularly in practical occupational contexts.

TABLE 1. The search string

Database	Search string
Scopus	TITLE-ABS-KEY ((worker* OR “workforce” OR “employee” OR “staff” OR “labor”) AND (behaviour* OR “behavioral” OR “conduct” OR “actions” OR “practices”) AND (“personal protective equipment” OR PPE OR “safety gear” OR “protective gear” OR “safety equipment”)) Date of Access: April 2026
Web Of Science	Results for TS=((“worker behavior” OR “worker behaviour” OR “employee behavior” OR “employee behaviour” OR “workplace behavior” OR “workplace behaviour” OR “occupational behavior” OR “occupational behaviour” OR “safety behavior” OR “safety behaviour” OR “protective behavior” OR “protective behaviour” OR “worker compliance” OR “safety compliance” OR behavior* OR attitude* OR perception* OR awareness OR knowledge OR practice* OR compliance OR adherence) AND (“personal protective equipment” OR PPE OR “protective equipment” OR “protective gear” OR “protective clothing” OR “safety equipment” OR respirator* OR glove* OR helmet* OR mask* OR goggles OR “face shield*” OR “safety boot*” OR “protective device*”)) Date of Access: April 2026

Table 2 shows that the inclusion of multiple subject areas underscores the interdisciplinary nature of this research field. Contributions in engineering and environmental science have traditionally focused on the design of PPE, material behaviour, and exposure control, while the social sciences and medical research are now beginning to address compliance, ergonomics, cognitive workload, and the health effects of prolonged PPE use. This intersection of fields indicates a broader paradigm shift in the study of occupational safety towards more integrated human-technology systems and socio-technical risk-control strategies.

Although the literature expanded greatly in size and variety, bibliometric data also indicate a continuing lack of cohesion among fields and research cultures. The relationship between behavioural theories, principles of ergonomic design, and organisational safety frameworks is often explored individually, with little cross-referencing between technical and behavioural research. This segregation could be one reason why laboratory-based PPE performance does not match performance in practical settings, as empirical studies have found. These results indicate the need for more integrative research agendas spanning engineering design, behavioural science, and occupational health policy.

In general, this bibliometric review indicates that worker behaviour has become a central topic in studies on PPE effectiveness, shifting from the margins to the centre of current occupational safety research. This study emphasises the maturity of the field and highlights opportunities for integrating theory and methods by mapping nearly 56 years of scientific output. In future studies, examining the origins of interdisciplinary cooperation, conducting longitudinal behavioural studies, and including real-world performance data could improve the applicability of PPE research as a safety intervention in the workplace.

IDENTIFICATION

To conduct the systematic literature review, a rigorous and structured review protocol was implemented to ensure the comprehensive retrieval of relevant scholarly publications. The review process commenced with the identification and selection of appropriate keywords, followed by the expansion of related terminologies through dictionaries, thesauri, encyclopaedias, and prior empirical studies to enhance the breadth and sensitivity of the search strategy. Subsequently, all relevant terms were systematically integrated into search strings and applied to the Web of Science and Scopus databases, as presented in Table 1. This rigorous identification process generated a total of 139,703 publications from both databases, reflecting the extensive and multidisciplinary nature of research related to the study domain. The use of multiple databases and comprehensive search terms strengthened the transparency, reliability, and methodological robustness of the systematic review process while minimizing the risk of database selection bias.

TABLE 2. The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Subject	Medical Engineering Social science, Environmental science Public environmental occupational safety and health	Others
Timeline	1970-2026	Before 1970

SCREENING

Following the identification stage, a rigorous screening process was conducted to enhance the relevance, quality, and methodological consistency of the retrieved literature. After applying the predefined inclusion and exclusion criteria, 1,748 records from Scopus and 9,492 records from Web of Science were retained, resulting in a total of 11,240 records eligible for further assessment. A substantial number of records ($n = 128,463$) were excluded due to being non-English publications, published before 1970, conference papers, books, review articles, articles in press, or studies unrelated to the research scope. These exclusion criteria were methodologically justified to ensure the inclusion of peer-reviewed, accessible, and empirically robust studies aligned with the objectives of the systematic review. Additionally, 2,739 duplicate records were removed to avoid data redundancy and publication overlap across databases. This rigorous screening approach strengthened the reliability, transparency, and scientific validity of the review process, ensuring that only high-quality and contextually relevant studies were retained for subsequent analysis.

ELIGIBILITY

In the third stage, known as the eligibility phase, a total of 8,501 articles underwent detailed evaluation. During this process, the titles, abstracts, and main content of each article were systematically examined to ensure alignment with the inclusion criteria and the objectives of the present study. As a result, 7,265 articles were excluded for reasons such as irrelevance to the research field, insignificant or unrelated titles, abstracts that did not address the study objectives, lack of full-text access, and insufficient empirical evidence. This rigorous assessment process was essential to ensure the methodological quality, relevance, and reliability of the selected literature. After the eligibility assessment, 1,236 articles were retained for the final review and analysis.

DATA ABSTRACTION

An integrative analysis approach was employed as a key assessment strategy in this study to examine and synthesise evidence from diverse qualitative research designs systematically. The primary objective of this approach was to identify significant themes and subthemes related to worker behaviour and the effectiveness of personal protective equipment (PPE). The thematic development process began with a comprehensive data collection stage, as illustrated in Figure 1, in which the authors meticulously

reviewed and analysed 1,236 selected publications to identify statements, findings, and evidence relevant to the study's scope. Particular emphasis was placed on critically evaluating contemporary studies addressing worker behaviour and PPE effectiveness, including their methodological approaches, analytical frameworks, and research outcomes. The authors then collaboratively developed thematic categories based on the empirical evidence and contextual interpretations emerging from the reviewed literature. Throughout the analytical process, a systematic audit trail was maintained to document analytical reflections, interpretations, emerging patterns, and conceptual considerations relevant to data interpretation. To ensure the reliability and consistency of the thematic development process, the authors continuously compared and refined the identified themes. Any discrepancies or disagreements regarding thematic interpretation were resolved through critical discussion and consensus among the co-authors, thereby strengthening the methodological rigour, transparency, and credibility of the study findings.

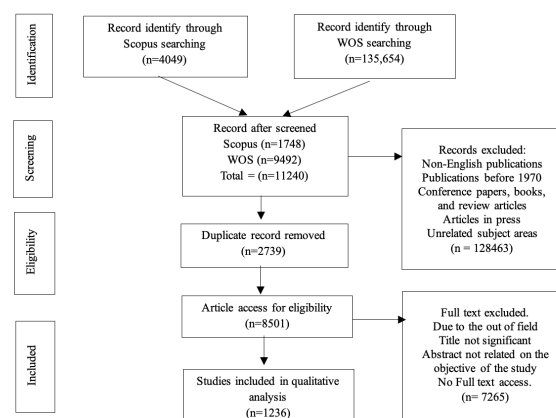


FIGURE 1. Prisma flow diagram for study selection

FIGURE 1. Prisma flow diagram for study selection

DATA ANALYSIS

VOSviewer is an established bibliometric analysis tool developed by Nees Jan van Eck and Ludo Waltman of Leiden University in the Netherlands (Van Eck & Waltman 2017). It is designed for the visualisation and exploration of scientific literature using network-based visualisations, clustering algorithms, and density-based mapping algorithms. Its analytical features allow exploration of patient co-authorship, co-citation associations, and co-occurring keywords across research fields, enabling users to study the structural makeup and intellectual organisation of their research areas. VOSviewer, with its dynamic

software update system and interactive user interface, enables efficient handling and interpretation of large bibliometric datasets. Its control over the generation of bibliometric measures, customisation of visual objects, and processing of information from various types of bibliographic resources has led to its adoption across numerous academic fields.

Among the key strengths of VOSviewer is its ability to transform complex bibliometric data into clear, understandable visual maps that illustrate the associations among publications, authors, and thematic areas. The software excels at clustering similar entities, identifying thematic patterns through keyword co-occurrence analysis, and generating density visualisations that reflect areas of intended research activity. It has an intuitive design that enables access for users with varying levels of bibliometric knowledge, and its continuous development ensures it remains aligned with the changing needs of the analytical process. The versatility of VOSviewer in supporting various types of bibliometric networks, such as co-authorship and citation-based networks, demonstrates its value as a fundamental analytical tool for studying the development of research domains.

In the present study, bibliographic records including publication year, article title, author information, journal source, citation metrics, and author keywords were exported from the Scopus database in plaintext format, covering articles published from 1970 to 2026. VOSviewer 1.6.19 was used to process these datasets. Bibliometric networks were visualised and analysed using visualisation of similarities, VOS-based clustering, and mapping methods. VOSviewer, as an alternative to traditional multidimensional scaling (MDS) techniques, places items in a low-dimensional space so that the spatial distance between any two items reflects their relatedness or similarity (Van Eck & Waltman 2007). In that regard, the VOS method demonstrates conceptual similarities to MDS methods (Appio et al. 2014).

In contrast to traditional methods of MDS, which generally rely on similarity measures such as cosine similarity or Jaccard indices, the VOS method uses a specially designed normalisation strategy based on bibliometric co-occurrence data, also known as association strength (AS; Van Eck & Waltman 2007). The AS between items i and j is determined as shown in Equation (1), where C_{ij} denotes the frequency with which items i and j co-occur, while w_i and w_j represent the total occurrence counts of items i and j , respectively. This indicator reflects the proportional relationship between the empirically observed co-occurrence frequency and the expected co-occurrence frequency under the assumption of statistical independence,

thereby providing an effective normalisation method for the construction and visualisation of bibliometric networks (Van Eck & Waltman 2007).

$$AS_{ij} = \frac{C_{ij}}{w_i \times w_j} \quad (1)$$

RESULTS AND DISCUSSION FINDINGS

RQ1: What are the temporal publication trends in research on worker behaviour and PPE effectiveness over time?

The publication trend for research on worker behaviour and PPE effectiveness shows a prolonged formative phase, followed by a marked period of rapid expansion. From 1970 to the early 2000s, scholarly output was sporadic and limited, with most years recording fewer than five publications. This low and irregular productivity reflects the initial approach to PPE as primarily a technical control, with limited attention to behavioural aspects. Progressive development has been observed since 2006, when the importance of human factors, safety culture, and behavioural science in occupational health research began to be acknowledged. The number of publications per year between 2010 and 2018 grew slightly but consistently, suggesting that the field is becoming more consolidated and that the importance of worker behaviour for the real-world efficacy of PPE is increasingly recognised. As shown in Figure 2, this upward trajectory becomes particularly evident after 2010, reflecting the increasing consolidation of research in this field.

The number of publications increased significantly from 2019, peaking in 2021 at 230 articles, and remained high through to 2024. This steep rise corresponds with global occupational safety issues and increased research interest during and after the COVID-19 pandemic, which heightened concern about PPE compliance, usability, and behavioural determinants across various work environments. Although publication levels are lower after 2021, they remain much higher than those before 2019, indicating fairly stable scholarly performance, rather than a sudden increase. The reduced number in 2026 is probably due to unfinished indexing rather than a decline in the research volume. Overall, the trend demonstrates a clear shift from an emerging niche to a mature, highly active research field, highlighting the growing centrality of behavioural perspectives in the development of PPE effectiveness research. This trend is consistent with previous bibliometric studies, which reported a gradual shift from technical safety research to behaviour-oriented approaches. However, the

magnitude of the increase observed after 2019 in this study appears more pronounced, suggesting an accelerated transformation driven by global health crises such as COVID-19.

The observed publication growth also indicates that research on PPE effectiveness has increasingly shifted towards interdisciplinary and behaviour-oriented perspectives. This trend highlights the growing recognition that occupational safety outcomes are strongly influenced by human factors, organisational practices, and workplace

safety culture, rather than relying solely on technical protection measures. This trend is consistent with previous studies that highlight the increasing importance of behavioural factors in PPE use and occupational safety, particularly regarding compliance, risk perception, and safety culture (Kibirige et al. 2024; Seah et al. 2025). However, the magnitude of the increase observed after 2019 in this study appears more pronounced, suggesting an accelerated transformation driven by global health crises such as COVID-19.

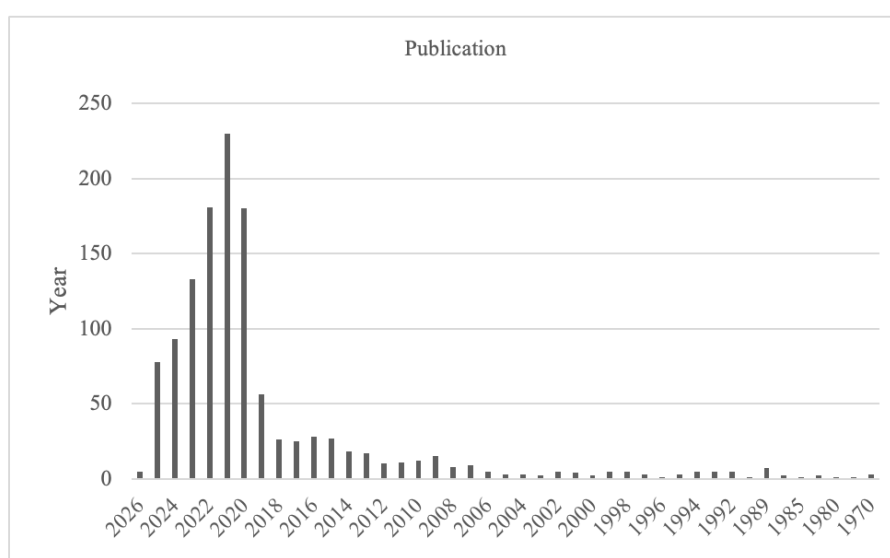


FIGURE 2. Trend of research in worker behaviour and personal protective equipment effectiveness

RQ2: Which publications are the most influential in this research domain based on citation analysis?

The discussion of the highest-rated articles shows that the scholarly impact of research on worker behaviour and the efficacy of PPE consistently depends on articles published during and immediately after major global safety and health crises, particularly around 2020 - 2021. As summarised in Table 3, the most highly cited articles were predominantly published between 2020 and 2021 and appeared in high-impact interdisciplinary journals. The most referenced articles are mainly found in high-impact journals such as *Science of the Total Environment*, *Automation in Construction*, *Environmental Pollution*, and *Headache*, which suggests that PPE behavioural research is reflected across the environmental science, engineering, and medical fields. Widely referenced articles often discuss the use of PPE within a broader system framework, such as occupational safety management, real-time monitoring technologies, and the health effects of long-term PPE use. The prevalence of articles published in 2020 highlights the catalytic role of the COVID-19 pandemic, which sparked scholarly interest in PPE compliance, usability, and worker behaviour in both healthcare and industrial settings, leading to increased citation activity over a limited period.

Thematically, the most cited articles move beyond the traditional view of PPE as a passive protective barrier, instead describing its effectiveness as a result of human behaviour, system design, and interactions with the environment. Research linking PPE use to physical discomfort, cognitive challenges, and adverse health effects, including headaches and fatigue, has received substantial citations, highlighting increasing concern about the sustainability of long-term PPE use. At the same time, the most cited articles in the engineering field emphasise the need to integrate behavioural factors into technological solutions, such as automation, real-time detection, and safety monitoring systems. The citation pattern indicates that the most significant contributions are those adopting an interdisciplinary approach to bridge human factors, engineering design, and occupational health. Overall, the dominance of such articles indicates a maturation of the field towards socio-technical interpretations of PPE effectiveness, in which worker behaviour is recognised as a critical determinant of safety outcomes rather than a secondary or peripheral factor. This finding is consistent with previous

studies, which show that highly cited publications are often associated with global health crises and interdisciplinary research contexts. For example, several influential studies published during the COVID-19 period (Ong et al. 2020; Rowan & Laffey 2020; Silva et al. 2020) highlight the increasing relevance of PPE not only in terms of technical performance but also in relation to behavioural, environmental, and health-related challenges. Similarly,

studies such as Hoernke et al. (2021) and Tabah et al. (2020) emphasise the practical experiences and safety concerns of PPE users, reinforcing the importance of human factors in determining effectiveness. The presence of earlier foundational work by Foo et al. (2006) and Tomas et al. (2015) further indicates that current research builds upon established knowledge while expanding towards more interdisciplinary and behaviour-focused perspectives.

TABLE 3. Most cited publications

No	Authors	Title	Year	Source title	Cited by
1	Silva et al. (2020)	Rethinking and optimizing plastic waste management under the COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment	2020	Science of the Total Environment	478
2	Nath et al. (2020)	Deep learning for site safety: Real-time detection of personal protective equipment	2020	Automation in Construction	406
3	Rowan and Laffey (2020)	Challenges and solutions for addressing the critical shortage of supply chain for personal and protective equipment (PPE) arising from the Coronavirus disease (COVID-19) pandemic – Case study from the Republic of Ireland	2020	Science of the Total Environment	369
4	Ong et al. (2020)	Headaches Associated With Personal Protective Equipment – A Cross-Sectional Study Among Frontline Healthcare Workers During COVID-19	2020	Headache	351
5	Ammendolia et al. (2021)	An emerging source of plastic pollution: Environmental presence of plastic personal protective equipment (PPE) debris related to COVID-19 in a metropolitan city	2021	Environmental Pollution	277
6	Tomas et al. (2015)	Contamination of health care personnel during removal of personal protective equipment	2015	JAMA Internal Medicine	257
7	Tabah et al. (2020)	Personal protective equipment and intensive care unit healthcare worker safety in the COVID-19 era (PPE-SAFE): An international survey	2020	Journal of Critical Care	249
8	Foo et al. (2006)	Adverse skin reactions to personal protective equipment against severe acute respiratory syndrome - A descriptive study in Singapore	2006	Contact Dermatitis	248
9	Singh et al. (2020)	Environmentally Sustainable Management of Used Personal Protective Equipment	2020	Environmental Science and Technology	216
10	Hoernke et al. (2021)	Frontline healthcare workers' experiences with personal protective equipment during the COVID-19 pandemic in the UK: A rapid qualitative appraisal	2021	BMJ Open	215

RQ3. Which countries are the leading contributors to the literature on worker behaviour and PPE effectiveness in terms of publication output and citation impact?

The country-level distribution of publications on worker behaviour and PPE effectiveness shows a strong concentration of research output among a small group of high-income, industrially advanced nations. As shown in Figure 3, research productivity is heavily concentrated in a small number of leading countries, with a clear disparity between high-output and low-output nations. The United States leads decisively with 357 publications, reflecting its extensive research infrastructure, regulatory focus on occupational safety, and sustained investment in worker protection studies. The United Kingdom and China are the next most productive contributors, followed by Australia and Canada, highlighting the role of well-established occupational health systems and active academic communities. The contributions of various European countries, such as Italy, Germany, Spain, and France, are also consistent, indicating sustained scholarly interest in worker behaviour and the effectiveness of PPE across different industry settings.

Conversely, the wider distribution has a long tail of countries with relatively low publication outputs, highlighting the continued global disparities in research capacity. The increasing participation of emerging economies such as India, Indonesia, Iran, Brazil, and South

Africa is associated with the rapid industrialisation and growing interest in workplace safety outcomes. However, many low- and lower-middle-income countries currently do not contribute a significant number of studies, which may indicate limited resources in funding, research infrastructure, and data accessibility. This imbalanced trend indicates that the existing evidence base is largely influenced by the views of developed economies, which justifies increased international cooperation and capacity-building to produce more context-dependent information on worker behaviour and PPE efficiency globally. This pattern is consistent with global research inequality trends reported in the bibliometric literature, where high-income countries dominate knowledge production because of stronger research infrastructure and greater funding availability. This pattern is consistent with previous studies conducted in global and international contexts, where developed countries largely drive research and policy discussions on PPE (Rowan & Laffey 2020; Silva et al. 2020; Tabah et al. 2020). These studies highlight how differences in resources, infrastructure, and international collaboration influence the distribution of research output and knowledge production among countries. The concentration of research activity in developed countries may also influence the global direction of PPE policies, research priorities, and occupational safety frameworks, potentially limiting the representation of workplace challenges experienced in lower-resource settings.

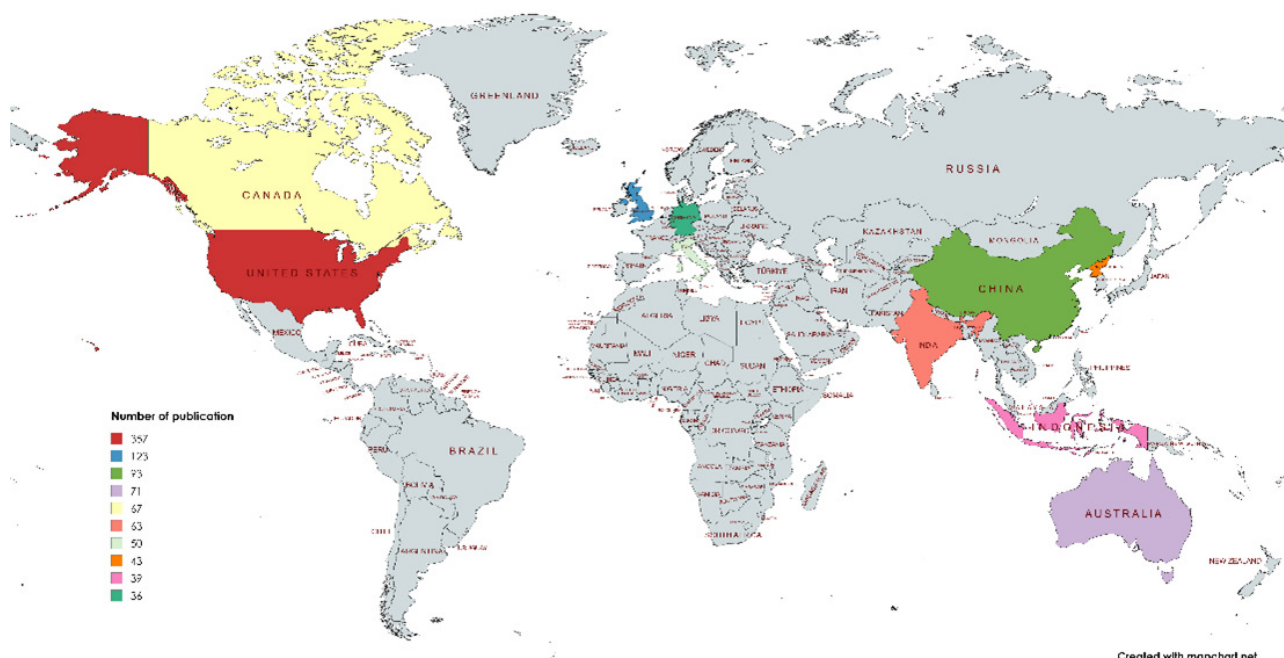


FIGURE 3. Countries are the leading contributors in terms of publications

RQ4. What are the most frequently occurring and thematically significant keywords, and how do they reflect the intellectual structure of research on worker behaviour and PPE effectiveness?

CONCEPT OF KEYWORD CO-OCCURRENCE IN VOSVIEWER

Co-occurrence by keywords in VOSviewer refers to the number of times two or more keywords appear together in the same publication. In this method, co-occurring keywords are expected to be conceptually related and to reflect common or interconnected research themes. The study of these connections allows VOSviewer to build a network in which each keyword is depicted as a node, and the connections between them indicate the intensity of their co-occurrence. The total link strength indicates the intensity of a keyword's relationship with others in the dataset. At the same time, the size of the node is usually proportional to the frequency of the keyword's appearance in the documents. To discuss worker behaviour and PPE effectiveness, the selected method helps display prevailing ideas, thematic groups, and the intellectual organisation of behavioural aspects and PPE-related terms in the literature. These findings can also be interpreted through established behavioural theories such as social cognitive theory (SCT), the health belief model (HBM), and the COM-B framework, which emphasise the role of individual beliefs, perceived risk, and environmental influences in shaping behaviour. This interpretation is consistent with previous studies that highlight the importance of human factors and user experiences in PPE effectiveness, particularly regarding compliance, safety practices, and physical or cognitive challenges (Hoernke et al. 2021; Ong et al. 2020; Tabah et al. 2020). Earlier studies, such as Tomas et al. (2015), further support the role of proper PPE use and handling in determining real-world effectiveness, reinforcing the relevance of behavioural constructs identified in the keyword analysis. The keyword structure shown in the co-occurrence network further indicates a significant conceptual transition within PPE research, where behavioural and organisational factors are increasingly integrated with technical and engineering perspectives. The strong association between keywords related to compliance, safety culture, risk perception, and human factors suggests that worker behaviour is no longer seen as a secondary issue, but rather as a central determinant of PPE effectiveness in real-world occupational settings. The identified keyword clusters further demonstrate the increasing relevance of behavioural theories in explaining PPE effectiveness. Keywords related to compliance, risk perception, and safety behaviour correspond closely with

key constructs of the health belief model (HBM), particularly perceived susceptibility and perceived barriers that influence protective actions. Similarly, the prominence of safety culture, communication, and organisational practices aligns with social cognitive theory (SCT), which emphasises observational learning, environmental influence, and behavioural reinforcement. In addition, the presence of motivation-, opportunity-, and capability-related concepts within the keyword network supports the applicability of the COM-B framework for understanding sustained PPE use across occupational settings. Collectively, these patterns suggest that effective occupational safety strategies depend not only on protective technologies but also on organisational practices, safety communication, and human-centred interventions that encourage long-term adherence and risk reduction.

SETTINGS USED TO GENERATE THE CO-OCCURRENCE MAP

The network visualisation was generated using the full-counting method, meaning that each occurrence of a keyword within a document was counted equally, regardless of how many other keywords appeared in the same publication. A minimum occurrence threshold of five was applied to ensure analytical robustness and to exclude infrequently used or highly idiosyncratic keywords that may not meaningfully contribute to the overall structure of the research field. The threshold was selected to improve the clarity and interpretability of the visualisation by focusing on recurrent and conceptually significant keywords within the dataset. As a result, 121 keywords met the threshold from a total of 2,392 identified keywords. This filtering process enables the map to focus on the most influential and recurrent concepts, producing a clearer and more interpretable visualisation of the core research themes and their interconnections within the field. Figure 4 shows the keyword co-occurrence network generated using VOSviewer, highlighting the major thematic clusters and their interrelationships.

CONTRIBUTION OF THE FINDINGS TO THE BODY OF KNOWLEDGE

The resulting co-occurrence network contributes to the body of knowledge by systematically mapping how worker behaviour, PPE usage, safety compliance, and effectiveness-related concepts are interconnected in existing research. High total link strength values indicate keywords that serve as conceptual hubs, suggesting areas where behavioural science and PPE effectiveness are most strongly integrated. This highlights dominant research directions, such as

behavioural compliance, risk perception, and safety culture, while also revealing underexplored or weakly connected themes that may represent gaps for future investigation. Overall, the findings provide an evidence-based overview of the intellectual structure of research on worker behaviour and PPE effectiveness, supporting more targeted research design, theory development, and evidence-informed occupational safety interventions. The keyword clustering patterns further suggest that contemporary PPE research is increasingly moving towards worker-centred and

behaviour-oriented approaches rather than focusing solely on equipment performance and hazard control. The prominence of behaviour-related keywords indicates that organisational culture, communication practices, worker perceptions, and behavioural compliance in real occupational environments strongly influence PPE effectiveness. This development highlights the growing importance of integrating behavioural science, ergonomics, and occupational safety management into PPE research and intervention strategies.

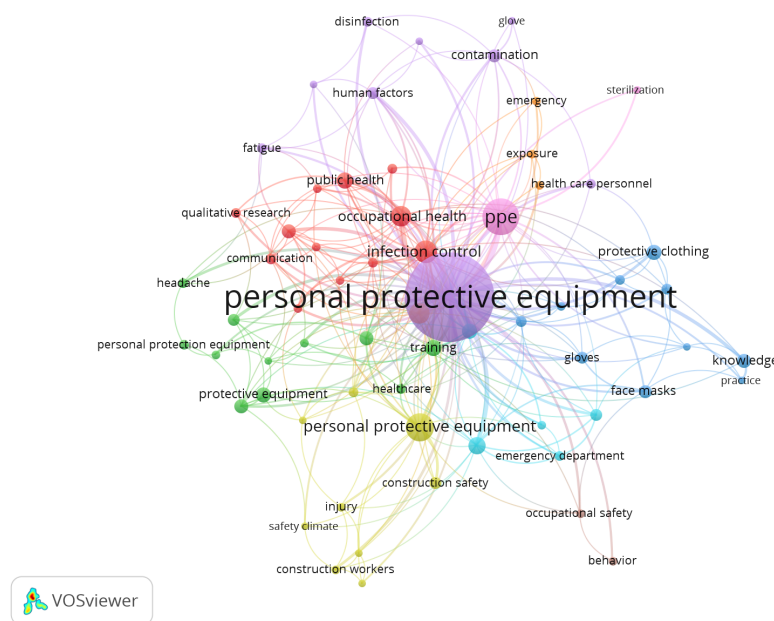


FIGURE 4. Network visualisation map of keyword co-occurrence

RQ5. What are the patterns of international co-authorship and collaboration among countries in research on worker behaviour and PPE effectiveness?

CONCEPT OF CO-OCCURRENCE BY COUNTRIES IN VOSVIEWER

In VOSviewer, *co-occurrence by countries* refers to the analysis of how countries are linked through co-authorship relationships within the same publications. When authors from different countries collaborate on a single document, those countries are considered to co-occur. The resulting network visualisation represents countries as nodes, while links indicate the strength of international research collaboration. The size of each node reflects the number of documents attributed to a country, while the total link strength represents the intensity of its collaborative ties with other countries. Regarding worker behaviour and PPE effectiveness, this methodology can show how research

collaboration is organised globally and which nations are most central to developing this area.

SETTINGS USED TO GENERATE THE COUNTRY CO-OCCURRENCE MAP

The full-counting method was used to produce the map, with each country present in a publication receiving full credit for that document, regardless of the number of countries contributing. This approach focuses on participation and visibility rather than proportional contribution. The inclusion criteria required a minimum of five documents to ensure that only countries with relevant research activity were included, eliminating noise from sporadic or isolated contributions. Consequently, the initial 101 identified countries were reduced to 48 that met the inclusion criteria. Filtering by threshold makes the visualisation clearer, and the network is considered to have only stable and meaningful international research

connections. Figure 5 shows the international co-authorship network among countries, highlighting the central hubs and the strength of collaborative links in this research domain.

CONTRIBUTION OF THE FINDINGS TO THE BODY OF KNOWLEDGE

The country co-occurrence network contributes to the body of knowledge by revealing trends in global collaboration on the study of worker behaviour and the effectiveness of PPE. Countries with a high number of publications and high total link strength become central hubs, indicating that they assume leadership roles in knowledge production and cross-border cooperation. Strongly knit clusters imply regional or thematic collaboration networks, whereas weak or peripheral links indicate regions where international cooperation remains limited. The results help put the

process of scientific knowledge in this field into perspective, from its global creation to its dissemination, and they guide policymakers, funding organisations, and researchers on areas of collaboration and the gaps to address in building stronger international research collaboration in the occupational safety and health field. These findings are consistent with previous studies highlighting the importance of international collaboration in addressing global PPE challenges. For example, studies conducted in international contexts by Rowan and Laffey (2020), Silva et al. (2020) and Tabah et al. (2020) demonstrate that cross-country cooperation and shared knowledge are essential for responding to complex issues such as PPE supply, safety practices, and crisis management. This supports the present findings, as countries with stronger collaboration networks tend to play more central roles in knowledge production and dissemination.

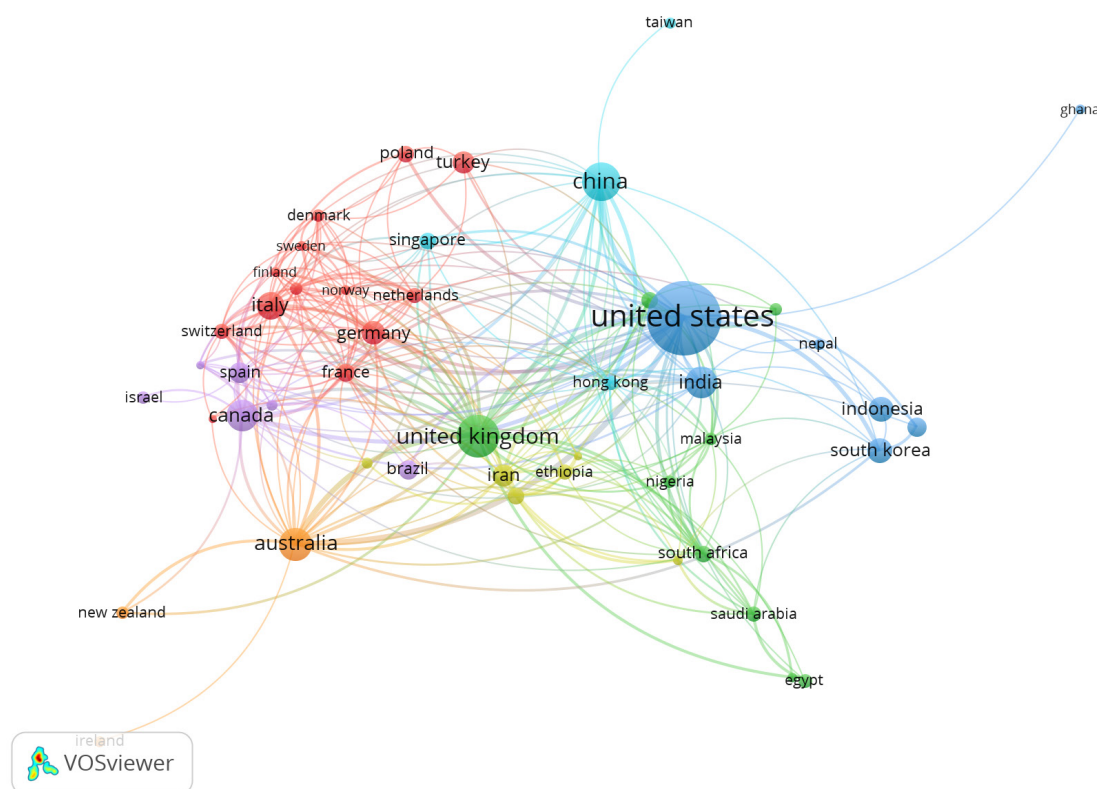


FIGURE 5. Network visualization map of citations and countries

CONCLUSION

This bibliometric analysis was conducted to investigate the development, contribution, thematisation, and cooperation trends in studies on worker behaviour and PPE

efficacy. The research aimed to answer key questions regarding publication patterns over the years, influential articles, leading contributing countries, popular keywords, and international co-authorship relationships. The analysis used bibliometric mapping and network visualisation methods to explain the development of this research area

and how knowledge is organised and shared globally.

The results show a significant and sustained increase in academic research, particularly since the late 2000s, with a sharp rise from 2019 onwards. This expansion indicates a growing appreciation that the effectiveness of PPE is strongly influenced by behavioural, organisational, and contextual factors and not necessarily by technical design. Citation analysis reveals that the most influential articles tend to take an interdisciplinary approach, linking the use of PPEs to human factors, health outcomes, and system-wide issues. At the country level, research production is concentrated in a few high-income countries. At the same time, keyword co-occurrence mapping highlights core themes such as compliance, safety culture, risk perception, and behavioural determinants. The collaboration analysis also shows the existence of international research hubs and areas with comparatively low levels of collaborative integration.

This study contributes to the field by offering a systematic review of the intellectual landscape concerning research on worker behaviour and the effectiveness of PPE. It summarises dispersed knowledge, identifies prevailing and emerging themes, and highlights gaps in research participation worldwide. In practical terms, the results underscore the need to integrate behavioural knowledge into the design of PPE, training initiatives, and safety management mechanisms. The findings can guide practitioners and policymakers to place greater emphasis on holistic safety strategies that encompass both technical protection and behavioural or organisational interventions.

Several limitations should be noted. Only English-language journal articles indexed in Scopus and Web of Science were included, which may still exclude some relevant regional, non-English, or non-indexed studies. Bibliometric analysis focuses more on publication and citation trends than on research quality or practical impact. Further studies could expand database coverage, include longitudinal behavioural evaluations, and use qualitative or mixed-methods approaches to better represent contextual and practical aspects of PPE use.

Overall, this bibliometric analysis demonstrates the value of systematic mapping for understanding the development and direction of research on worker behaviour and PPE effectiveness. By revealing trends, gaps, and collaboration patterns, the study provides a foundation for more integrated, context-sensitive research and supports the continued advancement of occupational safety and health scholarship.

ACKNOWLEDGMENT

There is no funding to support this study.

DECLARATION OF COMPETING INTEREST

None.

REFERENCE

- Akbarzadeh, O., Golzad, H., & Moshashaei, P. 2025. Health promotion model insights on determinants of personal protective equipment use in occupational settings. *Health Education and Health Promotion* 13(1): 103–110. <https://doi.org/10.58209/hehp.13.1.103>
- Al-Khoury, A., Hussein, S. A., Abdulwhab, M., Aljuboory, Z. M., Haddad, H., Ali, M. A., Abed, I. A., & Flayyih, H. H. 2022. Intellectual capital history and trends: A bibliometric analysis using Scopus database. *Sustainability (Switzerland)* 14(18). <https://doi.org/10.3390/su141811615>
- Alves, J. L., Borges, I. B., & De Nadae, J. 2021. Sustainability in complex projects of civil construction: Bibliometric and bibliographic review. *Gestao e Producao* 28(4). <https://doi.org/10.1590/1806-9649-2020v28e5389>
- Ammendolia, J., Saturno, J., Brooks, A. L., Jacobs, S., & Jambeck, J. R. 2021. An emerging source of plastic pollution: Environmental presence of plastic personal protective equipment (PPE) debris related to COVID-19 in a metropolitan city. *Environmental Pollution* 269, 116160. <https://doi.org/10.1016/j.envpol.2020.116160>
- Appio, F. P., Cesaroni, F., & Di Minin, A. 2014. Visualizing the structure and bridges of the intellectual property management and strategy literature: a document co-citation analysis. *Scientometrics* 101(1): 623–661. <https://doi.org/10.1007/s11192-014-1329-0>
- Assyakur, D. S., & Rosa, E. M. 2022. Spiritual leadership in healthcare: A bibliometric analysis. *Jurnal Aisyah : Jurnal Ilmu Kesehatan* 7(2). <https://doi.org/10.30604/jika.v7i2.914>
- Ayu, B. F., Tualeka, A. R., & Wahyudiono, Y. D. A. 2018. The analysis of factors which are related to the compliance of welder workers in using workplace personal protective equipment in Pt. Pal Indonesia. *Indian Journal of Public Health Research and Development* 9(5): 47–52. <https://doi.org/10.5958/0976-5506.2018.00410.2>
- Bentum, L., Brobbey, L. K., Adjei, R. O., & Osei-Tutu, P. 2022. Awareness of occupational hazards, and

- attitudes and practices towards the use of personal protective equipment among informal woodworkers: The case of the Sokoban Wood Village in Ghana. *International Journal of Occupational Safety and Ergonomics* 28(3): 1690–1698. <https://doi.org/10.1080/10803548.2021.1928390>
- Braun, C. C., & Fouts, J. W. 1998. Behavioral response to the presence of personal protective equipment: Implications for risk compensation. *Proceedings of the Human Factors and Ergonomics Society* 2, 1058–1062.
- Brisbine, B. R., Radcliffe, C. R., Jones, M. L. H., Stirling, L., & Colman, C. E. 2022. Does the fit of personal protective equipment affect functional performance? A systematic review across occupational domains. *PLoS ONE* 17(11): e0278174. <https://doi.org/10.1371/journal.pone.0278174>
- Bukhtiyarov, I. V., Kovalevsky, E. V., & Tskhomariia, I. M. 2023. Evaluation of the effectiveness of personal protective equipment and their impact on the health of medical workers. *Russian Journal of Occupational Health and Industrial Ecology* 63(12): 817–825. <https://doi.org/10.31089/1026-9428-2023-63-12-817-825>
- Curtis, K., Jansen, P., Mains, M., O'Hare, A., Scotcher, B., Alcorn, D., Nahidi, S., Harris, J., Brouillard, D., Morton, S., & Shaban, R. Z. 2022. Rapid development and implementation of a behaviour change strategy to improve COVID-19 personal protective equipment use in a regional Australian emergency department. *Australasian Emergency Care* 25(4): 273–282. <https://doi.org/10.1016/j.auec.2022.01.004>
- DellaValle, C. T., Andreotti, G., Alavanja, M. C. R., Hoppin, J. A., & Hines, C. J. 2012. Risk-accepting personality and personal protective equipment use within the agricultural health study. *Journal of Agromedicine* 17(3): 264–276. <https://doi.org/10.1080/1059924X.2012.686390>
- Denisov, E. I., Morozova, T. V., Adeninskaia, E. E., & Kur'arov, N. N. 2013. [The real-world effectiveness of personal protective equipment and additional risks for workers' health]. *Meditina Truda i Promyshlennaia Ekologiya* 4, 18–25.
- Di Stefano, G., Peteraf, M., & Veronay, G. 2010. Dynamic capabilities deconstructed: A bibliographic investigation into the origins, development, and future directions of the research domain. *Industrial and Corporate Change* 19(4): 1187–1204. <https://doi.org/10.1093/icc/dtq027>
- Fahimnia, B., Sarkis, J., & Davarzani, H. 2015. Green supply chain management: A review and bibliometric analysis. *International Journal of Production Economics* 162, 101–114. <https://doi.org/10.1016/j.ijpe.2015.01.003>
- Foo, C. C. I., Goon, A. T. J., Leow, Y.-H., & Goh, C.-L. 2006. Adverse skin reactions to personal protective equipment against severe acute respiratory syndrome - A descriptive study in Singapore. *Contact Dermatitis* 55(5): 291–294. <https://doi.org/10.1111/j.1600-0536.2006.00953.x>
- Giangreco, A., Carugati, A., & Sebastiano, A. 2010. Are we doing the right thing?: Food for thought on training evaluation and its context. *Personnel Review* 39(2): 162–177. <https://doi.org/10.1108/00483481011017390>
- Gu, D., Li, T., Wang, X., Yang, X., & Yu, Z. 2019. Visualizing the intellectual structure and evolution of electronic health and telemedicine research. *International Journal of Medical Informatics* 130. <https://doi.org/10.1016/j.ijmedinf.2019.08.007>
- Hoernke, K., Djellouli, N., Andrews, L., Lewis-Jackson, S., Manby, L., Martin, S., Vanderslott, S., & Vindrola-Padros, C. 2021. Frontline healthcare workers' experiences with personal protective equipment during the COVID-19 pandemic in the UK: A rapid qualitative appraisal. *BMJ Open* 11(1). <https://doi.org/10.1136/bmjopen-2020-046199>
- Khiste, G. P., & Paithankar, R. R. 2017. Analysis of bibliometric term in Scopus. *International Journal of Library Science and Information Management* 3(3): 81–88.
- Khorsandi, F., Farhadi, P., Denning, G., Grzebieta, R., Gibbs, J., Godler, Y., Heydinger, G. J., Hicks, D., Jennissen, C. A., Lundqvist, P., McIntosh, A., Rechnitzer, G., Simmons, K., & Yoder, A. M. 2025. Advancing all-terrain vehicles safety in agriculture: An insightful summary from global experts. *Journal of Agricultural Safety and Health* 31(3): 173–202. <https://doi.org/10.13031/jash.16119>
- Khoshakhlagh, A. H., Malakoutikhah, M., Park, J., Kodnoueieh, M. D., Boroujeni, Z. R., Bahrami, M., & Ramezani, F. 2024. Assessing personal protective equipment usage and its correlation with knowledge, attitudes, performance, and safety culture among workers in small and medium-sized enterprises. *BMC Public Health* 24(1). <https://doi.org/10.1186/s12889-024-19517-3>
- Kibirige, I., Niyitegeka, J., & Mutekanga, D. R. 2024. Compliance with personal protective equipment use among clay works employees. *Edelweiss Applied Science and Technology*, 8(6): 9062–9072. <https://doi.org/10.55214/25768484.v8i6.3934>
- Kirwan, C. 2025. Measuring the effectiveness of L&D: Time to move on from Kirkpatrick and Phillips? *International Journal of Training and Development* 29(1): 38–55. <https://doi.org/10.1111/ijtd.12342>
- Lee, Y.-A., Salahuddin, M., Gibson-Young, L., & Oliver, G. D. 2021. Assessing personal protective equipment needs for healthcare workers. *Health Science Reports* 4(3): e370. <https://doi.org/10.1002/hsr2.370>
- Lombardi, D. A., Verma, S. K., Brennan, M. J., & Perry, M. J. 2009. Factors influencing worker use of personal protective eyewear. *Accident Analysis and*

- Prevention 41(4): 755–762. <https://doi.org/10.1016/j.aap.2009.03.017>
- Lu, L., Shi, L., Han, L., & Ling, L. 2015. Individual and organizational factors associated with the use of personal protective equipment by Chinese migrant workers exposed to organic solvents. *Safety Science* 76, 168–174. <https://doi.org/10.1016/j.ssci.2014.11.025>
- Mayer, A., & Korhonen, E. 1999. Assessment of the protection efficiency and comfort of personal protective equipment in real conditions of use. *International Journal of Occupational Safety and Ergonomics* 5(3): 347–360. <https://doi.org/10.1080/10803548.1999.11076425>
- Nath, N. D., Behzadan, A. H., & Paal, S. G. 2020. Deep learning for site safety: Real-time detection of personal protective equipment. *Automation in Construction* 112. <https://doi.org/10.1016/j.autcon.2020.103085>
- Olson, R., Grosshuesch, A., Schmidt, S., Gray, M., & Wipfli, B. 2009. Observational learning and workplace safety: The effects of viewing the collective behavior of multiple social models on the use of personal protective equipment. *Journal of Safety Research* 40(5): 383–387. <https://doi.org/10.1016/j.jsr.2009.07.004>
- Ong, J. J. Y., Chandra, C., Goh, Y., Tang, J. Z. Y., Sooi, K. W. X., Tan, Y. L., Tan, B. Y. Q., Teoh, H.-L., Ong, S. T., Allen, D. M., & Sharma, V. K. 2020. Headaches associated with personal protective equipment – A cross-sectional study among frontline healthcare workers during COVID-19. *Headache* 60(5): 864–877. <https://doi.org/10.1111/head.13811>
- Ratu, D. N., Amelyawati, F., & Wahyudiono, Y. D. A. 2019. The analysis of the factors related to compliance of personal protective equipment usage at Pt X (steel companies) finishing area-sidoarjo. *Malaysian Journal of Medicine and Health Sciences* 15, 5–7.
- Rowan, N. J., & Laffey, J. G. 2020. Challenges and solutions for addressing critical shortage of supply chain for personal and protective equipment (PPE) arising from Coronavirus disease (COVID19) pandemic – Case study from the Republic of Ireland. *Science of the Total Environment* 725, 138532. <https://doi.org/10.1016/j.scitotenv.2020.138532>
- Santos, W., Lorente, A., Rojas, C., Mariscal, G., & Lorente, R. 2025. Impact of personal protective equipment in preventing occupational injuries: a systematic review and meta-analysis. *Frontiers in Public Health* 13, 1720363. <https://doi.org/10.3389/fpubh.2025.1720363>
- Seah, Y. Z., Yap, W. Y., Tan, Y. W., Zhao, Q., & Ong, L. S. 2025. Factors influencing personal protective equipment (PPE) use among blue-collar workers: an accessible survey. *BMC Public Health* 25(1). <https://doi.org/10.1186/s12889-025-24516-z>
- Sharma, M., Sharma, D., Sharma, A., Mohanty, A., Khapre, M., & Kalyani, C. 2022. Barriers faced by health-care workers in use of personal protective equipment during COVID pandemic at tertiary care hospital Uttarakhand, India: A qualitative study. *Journal of Education and Health Promotion* 11(74). https://doi.org/10.4103/jehp.jehp_406_21
- Silva, A. L., Prata, J. C., Walker, T. R., Campos, D., Duarte, A. C., Soares, A. M. V. M., Barceló, D., & Rocha-Santos, T. 2020. Rethinking and optimising plastic waste management under COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment. *Science of the Total Environment* 742, 140565. <https://doi.org/10.1016/j.scitotenv.2020.140565>
- Singh, N., Tang, Y., & Ogunseitan, O. A. 2020. Environmentally sustainable management of used personal protective equipment. *Environmental Science and Technology* 54(14): 8500–8502. <https://doi.org/10.1021/acs.est.0c03022>
- Tabah, A., Ramanan, M., Laupland, K. B., Buetti, N., Cortegiani, A., Mellinghoff, J., Morris, A. C., Camporota, L., Zappella, N., Elhadi, M., Póvoa, P., Amrein, K., Vidal, G., Derde, L., Bassetti, M., François, G., Ssi Yan Kai, N., De Waele, J. J., Ait Hssain, A. A., ... Garnacho-Montero, J. G. 2020. Personal protective equipment and intensive care unit healthcare worker safety in the COVID-19 era (PPE-SAFE): An international survey. *Journal of Critical Care* 59, 70–75. <https://doi.org/10.1016/j.jcrc.2020.06.005>
- Tessema, M., & Sema, W. 2022. Utilization of personal protective equipment and associated factors among large-scale factory workers in Debre-Berhan Town, Amhara Region, Ethiopia, 2021. *Journal of Environmental and Public Health* 2022, 8439076. <https://doi.org/10.1155/2022/8439076>
- Tomas, M. E., Kundrapu, S., Thota, P., Sunkesula, V. C. K., Cadnum, J. L., Mana, T. S. C., Jencson, A., O'Donnell, M., Zabarsky, T. F., Hecker, M. T., Ray, A. J., Wilson, B. M., & Donskey, C. J. 2015. Contamination of health care personnel during removal of personal protective equipment. *JAMA Internal Medicine* 175(12): 1904–1910. <https://doi.org/10.1001/jamainternmed.2015.4535>
- Van Eck, N. J., & Waltman, L. 2017. Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics* 111(2): 1053–1070. <https://doi.org/10.1007/s11192-017-2300-7>
- Van Eck, N. J., & Waltman, L. 2007. Bibliometric mapping of the computational intelligence field. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* 15(5): 625–645. <https://doi.org/10.1142/S0218488507004911>

- Wu, Y. C. J., & Wu, T. 2017. A decade of entrepreneurship education in the Asia Pacific for future directions in theory and practice. *Management Decision* 55(7): 1333–1350). <https://doi.org/10.1108/MD-05-2017-0518>
- Yaghoti, H., Tol, A., Sadeghi, R., Mazloumi, A., Foroushani, A. R., & Ghaderi, A. 2021. Assessing predictive factors of awareness in personal protective equipment use (PPEs) among workers employed at Iran Aluminium Company (IRALCO): Application of social cognitive theory. *Journal of Health and Safety at Work* 11(1): 13–25.