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Review

A Comprehensive Review of Ergonomics and Human Factors Engineering for Enhancing Comfort and Efficiency in Transport Systems

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Abstract: This research provides an integrated perspective on the application of ergonomics and human factors engineering (HFE) to enhance comfort and efficiency in military transport systems (MTS) and civilian transport systems (CTS), identified as imperative research needs. Comfort has become the definition of vehicle quality in CTS, while in MTS, comfort directly influences crew performance in operational environments, and protecting their health is essential. The study emphasizes the importance of adopting an integrative and scientifically grounded approach that eliminates systematic errors to meet user needs and ensure optimal vehicle performance in diverse operational settings. It further highlights how applying ergonomic principles optimizes human–machine interactions, improving user comfort and safety while providing a basis for future innovations in artificial intelligence and adaptive ergonomics. This study introduces a novel hybrid methodology combining bibliometric analysis and case studies to provide fresh insights into the application of ergonomics and human factors engineering, bridging gaps between civilian and military transport systems. This approach aims to promote efficiency, comfort, and performance in operational environments. The results confirm the research hypotheses, demonstrating that ergonomic principles and human factors engineering (HFE) can significantly enhance the comfort, safety, and performance of vehicle users in both civilian and military contexts.

Keywords: ergonomics; comfort; human factors engineering; performance in transport systems; comfort in transport systems

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1. Introduction

In the current context of automotive manufacturing engineering [1,2], characterized by rapid technological advancements and a significant increase in user expectations for comfort and efficiency, the integrated study of ergonomics and human factors engineering (HFE), because of human–vehicle interactions, has become an imperative necessity. In this context, comfort has become the definition of vehicle quality, with the difference between various vehicle models on the market being determined by comfort. Furthermore, in the current context of special-purpose vehicles, operational performance is dictated by the well-being of the crew, resulting from the continuous correlation and calibration of human–machine

interactions. In this regard, a conceptual distinction between the two sciences must be clarified: ergonomics focuses on adapting design to the physical characteristics of users to optimize comfort and performance, while human factors engineering addresses the cognitive interaction between humans and systems, evaluating how information is perceived and processed to improve system interface and operability.

While previous research has extensively explored ergonomics in either military or civilian systems, few studies have integrated the two to assess shared challenges and synergies. This study fills this gap by applying an integrative approach to both fields, offering a unified framework for improving transport system design.

This study is based on investigating how comprehensive approaches in the field of ergonomics can transform the interaction between humans and vehicle systems, significantly contributing to the optimization of user experience and overall system performance, as well as ensuring performance in operational environments, a crucial element for the current military context. Moreover, this commitment to ergonomic practices is reflected in increased customer satisfaction and broader adoption of innovative technologies, thereby facilitating a smooth transition to the era of autonomous and connected vehicles [3–5].

The purpose of this article is to provide a comprehensive analysis of ergonomic principles and human factors engineering, highlighting how their application can improve comfort, safety, and efficiency in both civilian and military transport systems. The specific objectives include evaluating the impact of ergonomic principles on human–machine interactions in various operational contexts; analyzing the contributions of human factors engineering to optimizing operational performance and user satisfaction; Identifying research gaps and trends through an extensive bibliometric analysis; and proposing innovative solutions for autonomous and connected transport systems.

This study employs a hybrid methodology, combining bibliometric analysis with case studies to explore trends and gaps in the field. The bibliometric analysis was conducted by selecting and filtering a significant volume of relevant scientific works from 1950 to April 2024. Case studies complement this analysis by providing concrete examples of the applicability of ergonomic principles and human factors engineering. The implementation of the most effective solutions for improving safety, comfort, and operational performance on the battlefield has experienced continuous development through innovations and challenges in adapting to changing needs. In this study, ergonomics and human factors engineering are approached as essential and complex fields with a crucial role in the continuous calibration of human–machine interactions to ensure that technological advancements effectively and responsibly meet the needs, comfort, and performance of users. Moreover, this study also examined military transport systems and the methods of optimization to achieve performance in operational environments, a crucial aspect of the current military context.

2. Literature Review

In the 1950s [6], the establishment of human factors groups (sets of physical, cognitive, and social properties specific to humans, whose selection depends on their negative or positive impact on human performance within the human–machine system) was observed across various industries, particularly in aviation and the military. This initial phase marked an awareness of the need to adapt environments and products to human capabilities and needs. In 1956 [7], the establishment of the HFE department within Ford Motor Company represented a significant move toward integrating ergonomics into the automotive industry, thereby marking an increasingly widespread recognition of the importance of this field.

In the following decades, the 1960s and 1970s [8], there was a paradigm shift regarding product responsibility and safety. This included the implementation of implied warranties

on product safety, the introduction of the concept of strict manufacturer liability for defects, and the enactment of workplace safety legislation.

During the 1980s and 1990s [9], with the advent of personal computers and other information technologies, there was a significant focus on ergonomics in user interface design. During this period, the term "usability" was introduced into the literature, reflecting the growing interest in user experience and the efficiency of interaction with technology.

One of the greatest challenges in the field of automotive interior ergonomics identified by researchers in the 21st century is aging. Research in this area [10] reveals the effects of an aging driver population on vehicle design and road safety. The first part of the research presents a series of psychomotor experiments illustrating the sensory decline associated with aging; the second part provides demographic trends of the period studied (which extend exponentially to the present) and the relevant impact on specific aspects of passenger safety.

Starting in the 2000s [11,12] and continuing into the next decade, with the rapid advancement of transportation system technology and the introduction of new devices in vehicles, such as capacitive touch screens, there has been an increased need to adapt products to human requirements and capabilities. This is particularly reflected in growing concerns about driver distraction caused by new technologies integrated into vehicles.

Regarding military transportation systems, safety concerns have become a constant priority. Since the 1980s, human factors have been integrated into the design and evaluation process of safety factors for military vehicles, such as battle tanks (M1A1 Abrams) [13]. Additionally, advanced ergonomic measures have been implemented to reduce crew fatigue during missions [14].

For both military (MTS) and civilian transportation systems (CTS), there are specific regulations that outline design criteria concerning human capabilities and limitations, without constraining innovation in the design or selection of hardware, software, materials, and specific processes. These regulations effectively integrate the principles and practices of human factors engineering and are presented in a structured manner in Table 1.

Table 1. List of regulations for the ergonomic design of military and civilian transportation systems. Source: developed by the authors.

Regulation Code	Definition	Organization	Reference
MIL-PRF-38039	Systems, Illuminated, Warning, Caution, and Advisory, General Specification for	Department Of Defense (DOD) Specifications	[15]
MIL-L-85762	Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible	DOD Specifications	[15]
MIL-STD-882	System Safety	DOD Standards	[15]
MIL-STD-1179	Lamps, Reflectors and Associated Signaling Equipment for Military Vehicles	DOD Standards	[15]
MIL-STD-46855	Human Engineering Requirements for Military Systems, Equipment, and Facilities	DOD Standards	[15]
DOD-HDBK-743	Anthropometry of U.S. Military Personnel	DOD Handbooks	[15]
MIL-HDBK-1908	Definitions of Human Factors Terms	DOD Handbooks	[15]
29 CFR 1910	Occupational Safety and Health Standards	Code of Federal Regulations (CFR)	[16]

Table 1. *Cont.*

Regulation Code	Definition	Organization	Reference
49 CFR 571.101	Standard No. 101; Controls and Displays	(CFR)	[16]
49 CFR 571.108	Standard No. 108; Lamps, Reflective Devices, and Associated Equipment	(CFR)	[16]
2002/44/EC	Vibration	European Agency for Safety and Health at Work	[16]
NATICK/TR-13/018	Anthropometric Survey of U.S. Marine Corps Personnel: Methods and Summary Statistics	Natick and Surviac Technical Reports	[17]
NATICK/TR-15/007	Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics	Natick and Surviac Technical Reports	[18]
SURVIAC-TR-12-169	Joint Software Systems Safety Engineering Handbook	Natick and Surviac Technical Reports	[18]
NIOSH	Applications Manual for the Revised NIOSH Lifting Equation	National Institute for Occupational Safety and Health (NIOSH)	[18]
ANSI/HFES 100	Human Factors Engineering of Computer Workstations	Human Factors and Ergonomics Society	[19]
ANSI/HFES 200	Human Factors Engineering of Software User Interfaces	Human Factors and Ergonomics Society	[13]
ANSI/HFES 200.3	Interaction Techniques	Human Factors and Ergonomics Society	[20]
ISO 9241-210	Ergonomics of Human-System Interaction—Part 210: Human-Centered Design for Interactive Systems	International Organization for Standardization	[20]
ISO 9241-400	Ergonomics of Human-System Interaction—Part 400: Principles and Requirements for Physical Input Devices	International Organization for Standardization	[20]

During the period 2000–2005 [13,15–20], interdisciplinary research on human factors engineering, ergonomics, and vehicle comfort focused on addressing issues arising from emerging technological innovations. In this context, particular attention was paid to the impact that integrated devices such as telematics, Bluetooth, and OLED screens have on driver distraction [15]. Simultaneously, investigations were conducted on how adjustments in vehicle configurations and anthropometric characteristics influence driving posture [13,20–24], highlighting the imperative of ergonomic optimization to ensure both comfort and safety.

Between 2005 and 2010 [25–33], the field of HFE in vehicles saw substantial progress, with a significant applicability and integration of ergonomic concepts in industrial practices. The implementation of human engineering principles, safety assurance principles in heavy military vehicles, and the promotion of international standardization in human factors and ergonomics were key pillars of this period. Additionally, the development of advanced human factor modeling methods and research for the automation and ergonomic design of vehicle interiors emphasized the need for an integrative and holistic approach to improve the quality of the driving experience, focusing on passenger comfort, efficiency, and safety [25–33].

A significant issue in the ergonomic design of vehicles is the conceptualization of "humans as part of the system", where the designer treats the human factor as an integral

part of the system to be developed. This mode of analysis requires a comprehensive approach to the driver/user, vehicle, and surrounding environment during the design process. By incorporating the characteristics of each component of the system, including the human user, designers ensure that the vehicle meets user needs related to comfort, accessibility, and safety. Moreover, understanding the human–machine relationship and the vehicle's operating environment is crucial in the design process, ensuring that the system efficiently responds to user requirements during various tasks, preferences, and perceptions in diverse operating conditions. In this regard, an important conceptualization was made by researcher V.D. Bhise in 2011 [34], who proposed a model for optimizing vehicle design, which can be visualized in Figure 1. The diagram for evaluating vehicle interior ergonomics, conceptualized by the same researcher, is represented in Figure 2.

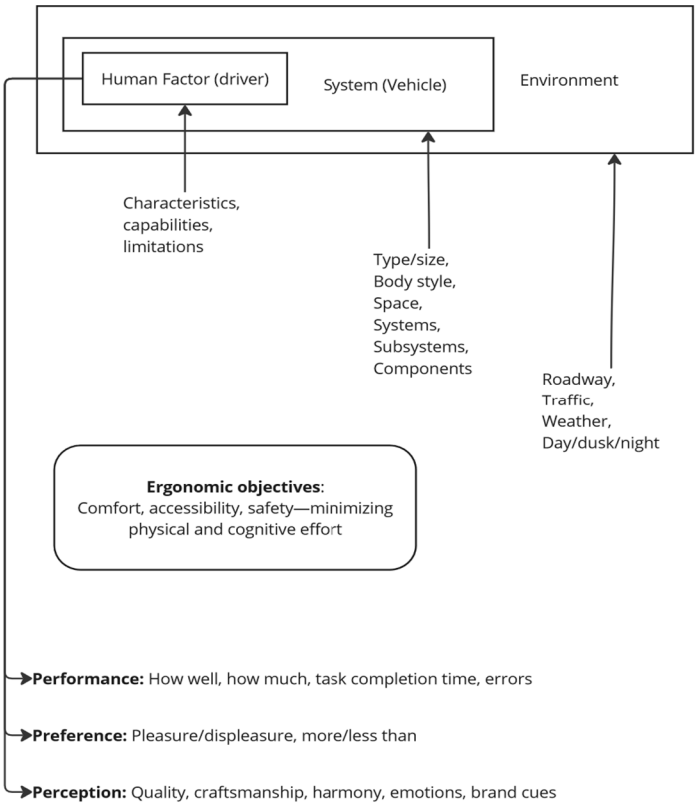


Figure 1. Conceptualization of automotive ergonomic design. Source: Ergonomics in the Automotive Design Process [34].

The objective of ergonomic evaluation in the vehicle design process is to refine the interaction between the vehicle and its occupants by adapting to the diversity of anthropometric characteristics and the complexity of users' functional needs, with the aim of enhancing performance and increasing the level of satisfaction experienced by operators during use. To this end, the study considers the presented conceptualization models.

Between 2010 and 2014 [33–36], research focused on the ergonomic design of vehicle interiors, addressing aspects such as adaptability to the diverse needs of users and their comfort. During the period 2017–2020 [37–39], interest was directed towards the development of advanced technologies and innovative methods for evaluating ergonomics in vehicle interiors, with an emphasis on electric and autonomous vehicles. Recent research [39–42] has adopted an integrated perspective on ergonomics and human psychology to optimize the design and operation of autonomous vehicles. This direction of study involved exploring advanced theories on cognitive load, attention resources, and the impact of task

automation on the driver, accompanied by increased attention to interface design and passenger monitoring.

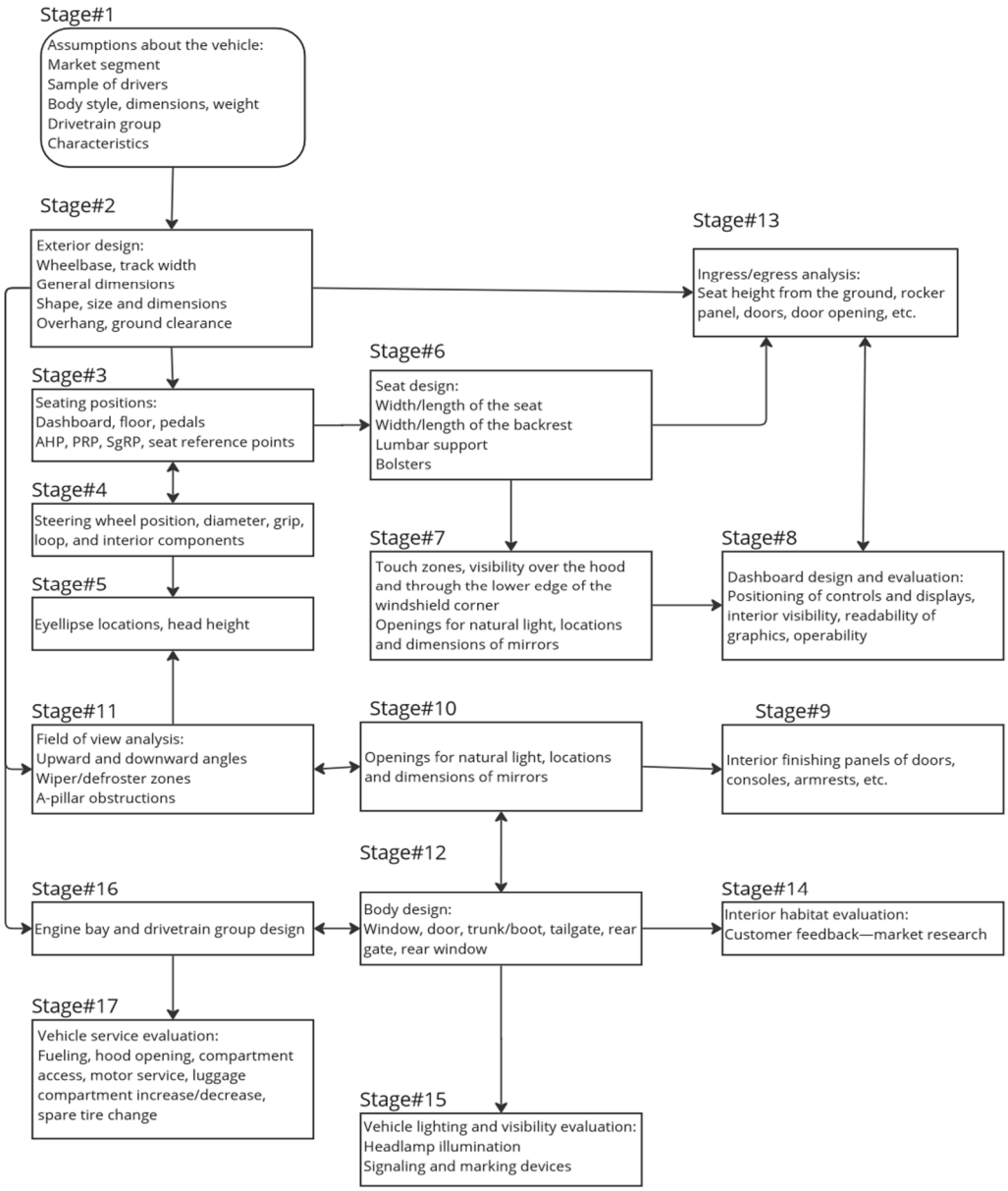


Figure 2. Conceptual diagram for evaluating vehicle interior ergonomics. Source: Ergonomics in the automotive design process [34].

On the other hand, recent research has evolved towards developing proactive strategies and designs aimed at optimizing the visibility, predictability, and maneuverability of autonomous vehicle systems. At the same time, special attention has been paid to the human systems integration (HSI) process by applying complex and innovative models aimed at improving the performance, efficiency, and safety of vehicles. These advances represent a significant step towards creating a safer, more efficient, and more personalized driving experience for users of autonomous vehicles.

A systematization of specialized literature and innovations by year of appearance concerning ergonomics in the automotive industry can be found in Table 2.

Table 2. List of innovations of interest in correlation with relevant publications in the evolution of vehicle design ergonomics. Source: developed by the authors.

Main Author	Year	Innovation Description	Specification	Reference *
Price et al.	1980	Formation of Human Factors groups in industry—especially in aviation and military sectors	Establishment of Human Factors research groups	[14]
Jarvis et al.	1984	Use of cathode ray tube (CRT) screens to display information in an advanced concept vehicle. CRT screens were used for primary, secondary information display, functional control, in-car navigation display, and rear-view display	Introduction of cathode ray tube screens in vehicles	[17]
Lyons et al.	1988	Integration of human factors and safety factor evaluation for the M1A1 Abrams main battle tank	Integration of human factors and safety factor evaluation in military vehicles	[18]
Reed et al.	2000	Investigation of how vehicle configuration adjustments and anthropometric characteristics significantly influence driving posture and prediction of the impact of design modifications on driving posture	Research on the impact of vehicle interior modifications on driving posture—Driving ergonomics	[13]
Shaheen et al.	2001	Identification of a major challenge in vehicle interior ergonomics: aging population and adoption of design solutions for vehicles to accommodate physical infirmities encountered by the elderly	Innovative ergonomic solutions in vehicle interiors for elderly drivers	[20]
Coelho	2002	Doctoral thesis: Research on the applicability of comfort, pleasure, and cognitive engineering theories in design engineering processes	Predictive factors in comfort through seat design modifications	[21]
Reed et al.	2002	Identification of an innovative driving posture prediction model that optimizes the placement of digital human figure models for vehicle interior design based on advanced statistical methods	Identification of an innovative driving posture prediction model for driver position design	[22]
Clark et al.	2005	Implementation of human factors engineering and safety engineering on heavy military vehicles	Adoption of human factors engineering principles and safety engineering on military vehicles	[23]
Sherehiy et al.	2005	Research for international standardization in human factors and ergonomics	International standardization in human factors and ergonomics	[24]
Lenior et al.	2006	Research on the application of cognitive engineering and ergonomic methods allows efficient task distribution and adaptive support to user needs	Application of ergonomic methods and cognitive engineering in developing adaptive support in transport systems	[25]
van der Meulen et al.	2007	Use of advanced 3D tools for quick and precise posture and comfort analysis, providing additional functions for seatbelt evaluation, compatibility with body laser scanners, and simulation of seat-occupant interactions	Use of the 3D tool RAMSIS for ergonomic analysis in vehicle interiors	[26]

Table 2. *Cont.*

Main Author	Year	Innovation Description	Specification	Reference *
Yang et al.	2007	Development of simulators for evaluating and optimizing human posture and movements for vehicle interior design for different user types	Use of simulators for evaluating and improving vehicle interior ergonomics	[27]
Wilson et al.	2007	Research on improving cockpit ergonomics by implementing adaptive automation systems	Implementation of adaptive automation systems in aircraft cockpits	[28]
Summerskill et al.	2008	Application of advanced human factor modeling methods in the design process of the rail industry to ensure interior ergonomics	Application of advanced human factor modeling methods for interior ergonomics in railway vehicles	[29]
Ho et al.	2008	Development of interfaces using cognitive neuroscience for human information processing, focusing especially on multisensory interactions and spatial attention distribution during driving	Implementation of multisensory interfaces to ensure vehicle interior ergonomics	[30]
Gan et al.	2009	Research on ergonomic design of vehicle seat surfaces	Ergonomic design of vehicle seat surfaces	[31]
Grujicic et al.	2009	Integrated approach to physiological factors and material use to ensure driving seat comfort	Improving driving seat comfort in vehicles through the use of materials and study of physiological factors	[32]
Onken et al.	2010	Research for automation and ergonomic design of vehicle interiors	Research for automation and ergonomic design of vehicle interiors	[33]
Bhise	2011	Investigations on human characteristics and limits, information processing by drivers and passengers, vehicle interior dimensions, lights and signals, user comfort, and vehicle design aspects	Principles of vehicle interior design using human factors engineering	[34]
Bey et al.	2012	Adoption of WIMPS interfaces—windows, icons, menus, pointer	Adoption of WIMPs interfaces in vehicles	[16]
Akbar et al.	2013	Implementation of ergonomic measures that reduced tank crew fatigue effects by 30% during operations. The study focused on the effects of vibrations and noise on crew performance and comfort	Implementation of ergonomic measures in military vehicles	[35]
Chen et al.	2014	Development of an advanced car seat system designed specifically to improve accessibility and comfort for elderly and disabled persons	Ergonomic principles for designing vehicles for disabled persons	[36]
Parnell et al.	2017	Driver distraction caused by new integrated devices in vehicles considered a major road safety issue by NHTSA. These devices include technologies such as telematics, Bluetooth, haptics, and OLED screens	Investigation of issues introduced by new technologies in ensuring vehicle interior ergonomics	[19]

Table 2. *Cont.*

Main Author	Year	Innovation Description	Specification	Reference *
Ćosevski et al.	2017	Studies and research on the ergonomic design of electric vehicle interiors	Research on the ergonomic design of electric vehicle interiors	[37]
Reuzeau	2018	Methods based on systems engineering, ergonomics, human–machine interaction (HMI) design, and graphic design in autonomous vehicle interior design	Ergonomic design of autonomous vehicle interiors	[38]
Muslim et al.	2019	Development of an optimal ergonomic design for vehicle interiors using eye-tracking method to evaluate the effectiveness of different designs	Optimal design minimizing the number of eye fixations and saccades, reducing response time, improving ergonomics and driver efficiency	[39]
Lesiuk et al.	2020	Development of a method for evaluating ergonomic reliability for passenger car interfaces, combining the entropy weight method (EWM) and multiple attribute decision making (MADM)	Ergonomic reliability evaluation of vehicle interfaces	[40]
Hussien et al.	2022	Establishment of the Human Factors Society (HFS) in the United States	Emergence of the Human Factors Society in the United States	[15]
Young et al.	2023	Integrated approach to ergonomics and human psychology in the design and operation of autonomous vehicles (theories on cognitive load and attention resources, impact of automation on driver performance, interface design in vehicles, driver monitoring, eco-driving, reactions to automation failures, and human-centered automation)	Integrated approach to ergonomics and human psychology in the design and operation of autonomous vehicles	[41]
Jahn et al.	2024	Coactive designs that optimize the visibility, predictability, and maneuverability of systems to enhance operational robustness (human support in interaction with autonomous systems, emphasizing the need for “wizard” interfaces and “shepherd raising” strategies to facilitate human intervention in incident and system failure management)	Coactive designs that optimize the visibility, predictability, and maneuverability of systems to enhance operational robustness in vehicles	[42]
Feng et al.	2024	Innovative approach using an input-process-output model to structure Human System Integration (HSI) processes in various stages of technology development, combining theory and practical application to improve human system performance, costs, and safety	Optimization of HSI processes in vehicles	[43]

* Legend: Red for GS citations $\geq$ 79, green for GS citations $\geq$ 48, black for GS citations $\leq$ 47.

The integrated analysis of ergonomics on one hand and human factors engineering on the other highlights the conceptual delineation of these two complementary fields and the evolution over time of a series of relevant studies regarding their impact on

transportation systems. Consequently, the integration of ergonomic principles and human factors engineering in vehicle design proves to be essential for optimizing the interaction between the operator and the system, significantly contributing to operational efficiency and reducing the incidence of human errors, despite facing limitations [44,45] imposed by anthropometric variations and rapid technological advancements. Future research directions focus on the continuous adaptation of these principles to address challenges related to autonomous vehicles and the advanced implementation of artificial intelligence.

With the advent of autonomous vehicle systems and the integration of AI-driven ergonomics, this study's insights into optimizing human–machine interaction have far-reaching implications for both current and future vehicle designs, enhancing user safety and comfort [46–50].

3. Research Objectives and Hypotheses

The aim of this study is to provide an integrated analysis of ergonomics and human factors engineering to enhance comfort, safety, and efficiency in transport systems, addressing both civilian and military applications. Specifically, this study seeks to:

1. Examine how ergonomic principles improve human–machine interactions in transport systems.
2. Evaluate the role of human factors engineering in optimizing operational performance and user satisfaction.
3. Identify trends and research gaps through bibliometric analysis to advance understanding in these fields.
4. Propose innovative solutions for autonomous and connected vehicle systems that meet evolving user demands.

Based on these objectives, the following hypotheses were formulated:

H0. *The application of ergonomic principles in vehicle design significantly enhances user comfort and performance, contributing to the reduction of human errors and the optimization of operational safety.*

H1. *Integrating human factors engineering into vehicle design optimizes human–machine interactions by adapting vehicle systems to the cognitive and physical capabilities of users, thereby increasing efficiency and user satisfaction.*

H2. *Utilizing an integrated approach in ergonomics and human factors engineering for civilian and military vehicles (CTS and MTS) leads to innovative solutions that improve comfort, safety, and performance in diverse and demanding operational environments.*

H3. *Technological advancements and the adoption of autonomous and connected vehicles increase the necessity for advanced ergonomic and human factors engineering solutions to address the new challenges of user interaction with automated systems.*

H4. *Bibliometric analysis enables the identification of trends and gaps in research regarding ergonomics and human factors engineering, thereby facilitating the development of evidence-based strategies for improving comfort and safety in vehicle design.*

4. Methodology

In recent years, interest in the fields of human factors engineering, ergonomics, and comfort assurance has significantly increased, with applications in transportation systems. In the previous chapter of the research, we presented evolution and innovations in these

fields, highlighting the significant contributions of fundamental research. In the context of current technological developments, it is essential that these fields be approached in an integrated manner to analyze and evaluate both limitations and innovative strategies in the transportation industry, with a particular focus on CTS (civilian transport systems) and MTS (military transport systems).

Although the literature is extensive regarding ergonomics, human factors engineering, comfort assurance, and their importance to the automotive industry, the correlations between the three fields are found in relatively few scientific analyses. The aim of this study is to integrate these three fields to formulate a comprehensive vision on the evolution and optimization of the interaction between the user and the vehicle.

The methodological approach adopted in this paper involves an exhaustive and systematic analysis of the specialized literature, through the selection and filtering of scientific works, driven by the necessity of precisely defining the problem and identifying relevant publications, to ensure a solid data foundation that supports the research results. A bibliometric review of the literature in this field of comfort research has been conducted from 1950 to April 2024. The research methodology follows the steps presented systematically in Figure 3. A similar procedure is adopted by Okoli and Schabram [51], who describe and define the procedure of systematic evaluation of innovations in certain fields as an analysis of a vast number of publications reviewed over a period, from which a large amount of data and information can be extracted for analysis. This makes it possible to collect relevant information through a well-defined objective approach, reducing systematic biases by identifying, evaluating, and synthesizing all relevant studies.

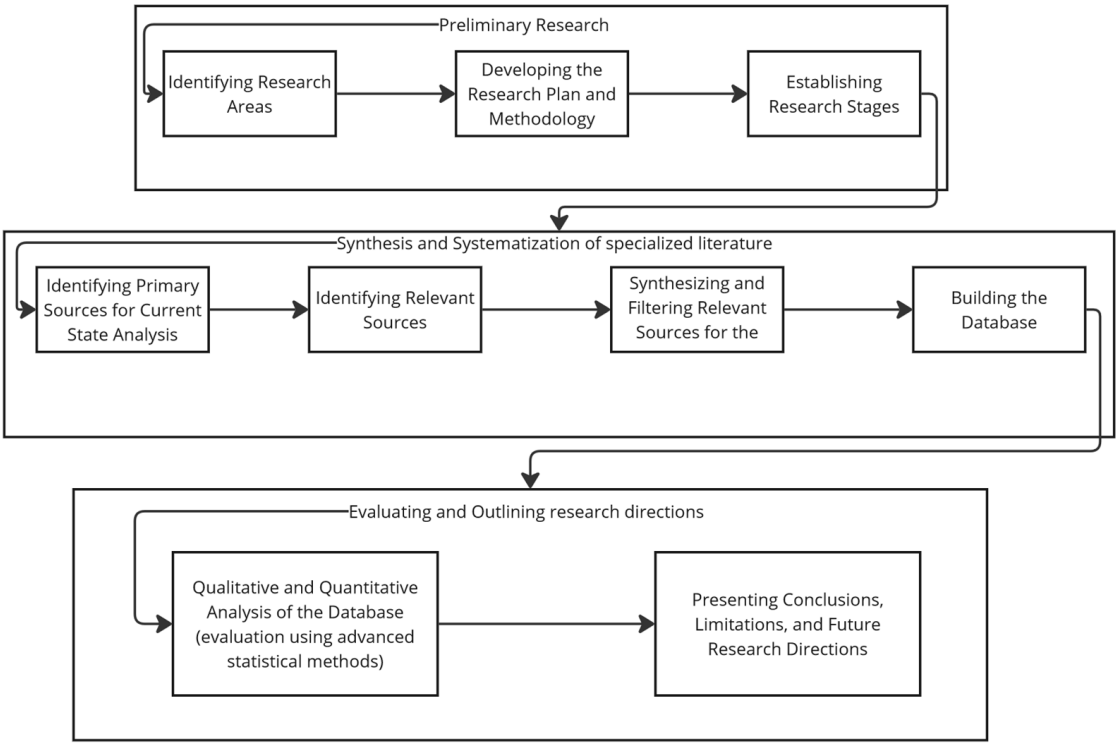


Figure 3. Quantitative and qualitative research methodology of CTS and MTS. Source: developed by the authors.

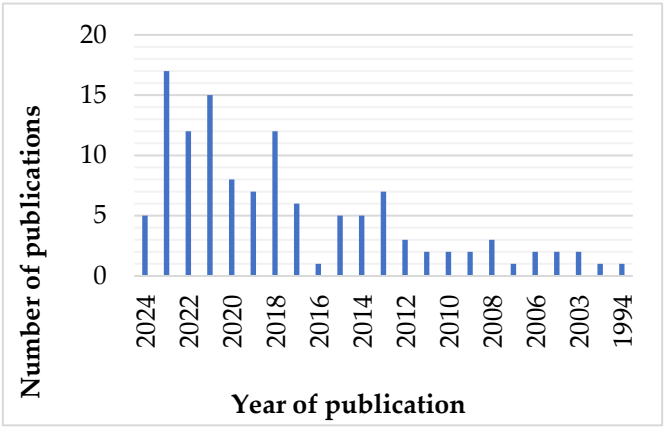
The proposed research methodology relies on a variety of statistical models for evaluating and interpreting research results, as follows:

- we applied descriptive statistics for frequency analysis of publications, citations, and keyword occurrences, as well as for determining central tendencies and measuring dispersion, including range, variance, and standard deviation for citations and publications;
- we employed network analysis for co-citation analysis to identify relationships within the analyzed research groups and for co-authorship analysis to determine collaboration patterns between countries and institutions based on joint publications;
- we applied regression analysis: linear regression to determine the relationship between the number of publications and citations and other qualitative and quantitative variables such as time and researcher demographics; multiple regression to examine the influence of various factors on publication and citation metrics;
- we used factor analysis through cluster analysis based on citation patterns and keywords;
- we applied time series analysis to the analyzed groups to identify trends and patterns in publication and citation data over time and long-term trends in research activity dynamics;
- we conducted bibliometric analysis and generated network graphs to represent co-citation, co-authorship, and bibliographic coupling relationships.

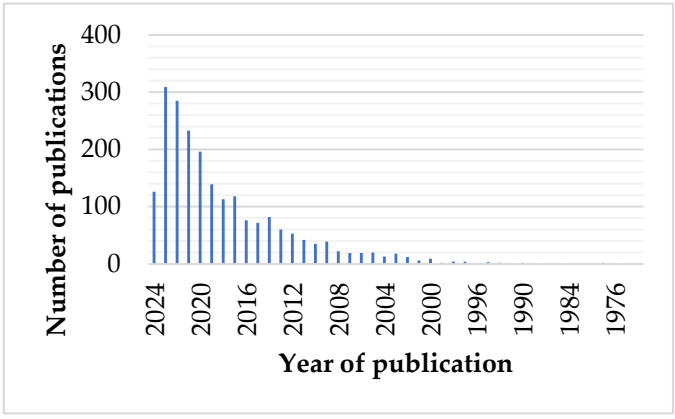
Comfort in automotive industry—A systematic analysis from the perspective of ergonomics and human factors engineering. In the synthesis and systematization stage, a detailed review of the specialized literature was conducted. The next step was to establish the main sources for analysis: Google Scholar, Scopus, and Web of Science.

A quantitative search of scientific publications was conducted during the analysis of the selected databases, according to the search query (which can be seen in Figure 4), generating over 30,000 relevant publications up to April 2024. Most publications were identified in the Google Scholar database (some of the innovations being presented in previous chapters) and far fewer in the Web of Science and Scopus databases. However, the considerable volume of results led to the definition of additional steps defined by qualitative attributes.

Conference papers, articles, books, research papers, and book chapters were considered. These types of publications were correlated with information such as the most frequently cited authors, the most frequently cited documents, the most productive countries, top institutions, common keywords, and abstracts of top publications. The results of the synthesis and systematization of the specialized literature as well as the analyzed fields can be found in Table 3. The study was applied to 11 analysis groups.

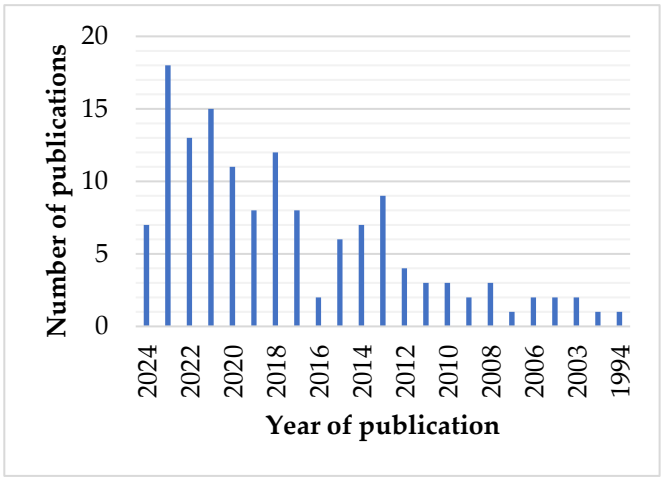


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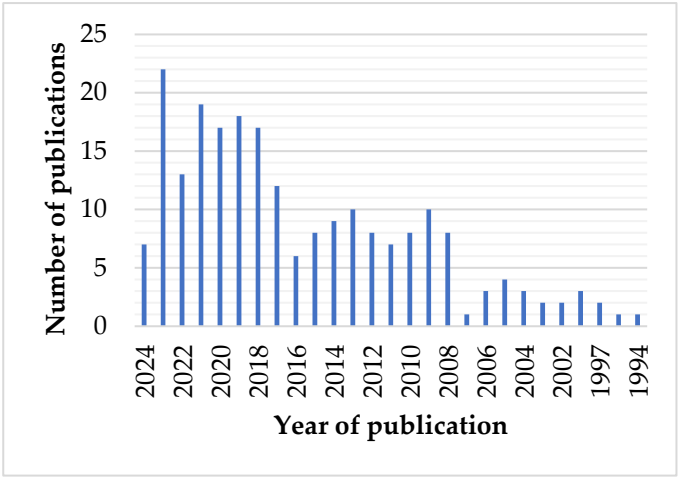


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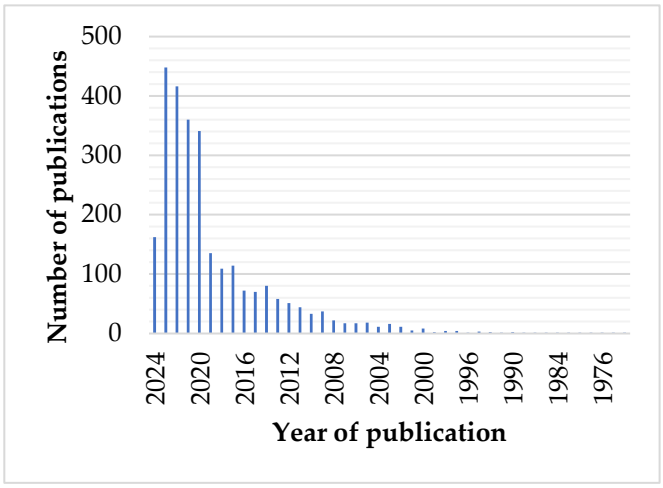
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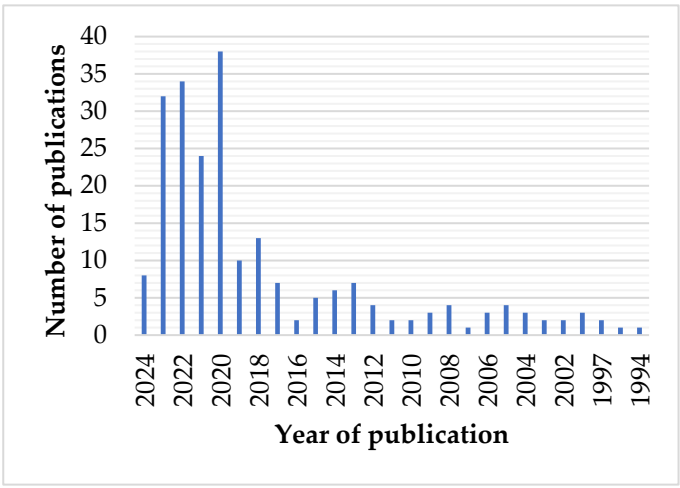
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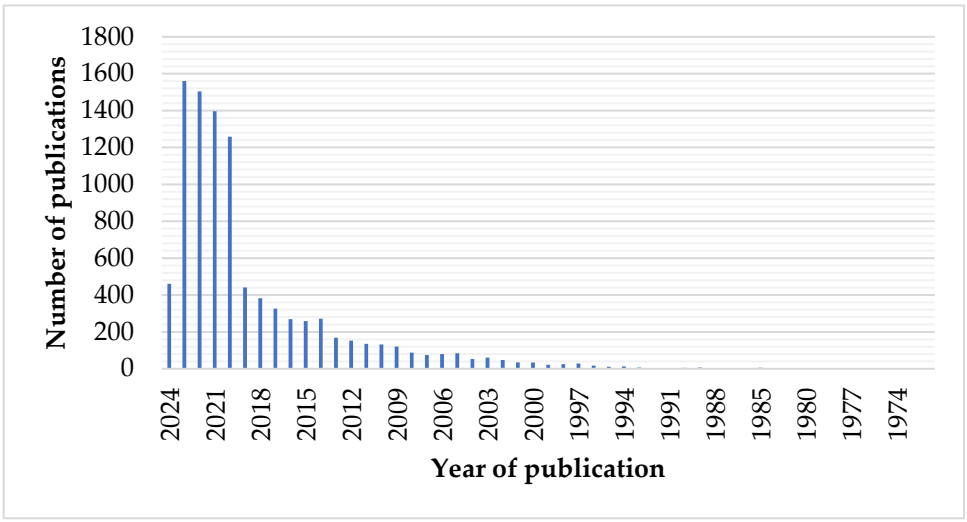
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(**f**)



(**g**)

Figure 4. Evolution over time of research on the application of ergonomics, human factors engineering, and comfort in MTS and CTS. Source: developed by authors. (**a**) Ergonomics, Human Factors Engineering, and Comfort. (**b**) Human Factors Engineering and Comfort. (**c**) Ergonomics and Human Factors Engineering. (**d**) Ergonomics and Comfort. (**e**) Human Factors Engineering. (**f**) Ergonomics. (**g**) Comfort.

Table 3. Synthesis and systematization of specialized literature regarding the application of ergonomics, HFE and comfort in MTS and CTS. Source: Scopus, Web of Science.

Analyzed Group	Search Terms	Reference Publications	
		Scopus	Web of Science
1. Ergonomics	(ergonomics AND vehicles) AND (ergonomics AND engineering AND vehicle)	148	372
2. Human Factors Engineering	(comfort AND vehicles) AND (human AND engineering AND vehicle)	2082	1894
3. Comfort	(comfort AND acoustic AND vehicles) AND (comfort AND vehicle)	6060	9784
4. Ergonomics AND Comfort	(comfort AND vehicles) AND (ergonomic AND comfort AND vehicle)	148	65
5. Ergonomics AND Human Factors Engineering	(comfort AND vehicles) AND (ergonomic AND human AND engineering AND vehicle)	119	21
6. Comfort AND Human Factors Engineering	(comfort AND acoustic AND vehicles) AND (comfort AND human AND engineering AND vehicle)	2082	77
7. Comfort, Ergonomics AND Human Factors Engineering	(comfort AND vehicles) AND (comfort AND human AND engineering AND ergonomic AND vehicle)	119	4
8. Thermal Comfort	(comfort AND vehicles) AND (thermal AND comfort AND vehicle)	1318	576
9. Vibrational Comfort	(comfort AND vehicles) AND (vibrational AND comfort AND vehicle)	407	62
10. Acoustic Comfort	(comfort AND vehicles) AND (acoustic AND comfort AND vehicle)	1438	196
11. Acoustic, Vibrational, AND Thermal Comfort	(comfort AND vehicles) AND (comfort AND vibrational AND acoustic AND thermal AND vehicle)	116	0

5. Results and Discussion

The analysis of the evolution of research in the field of comfort over time (Figure 4g) reveals a notable expansion of research, with exponential growth starting at the beginning of the 21st century, culminating in a 16% share in 2022 and 2023. This upward trend, reflected in a significant 5% share in 2024, although the year is still ongoing, denotes a continuous and increasing concern of the scientific community towards deepening and innovating in this sector, suggesting a synergy between technological development and prioritizing user experience in the transportation systems industry.

The evolution of investigations in human factors engineering applied to the automotive field indicates a significant and continuous increase in interest and academic activity in recent years, with a remarkable peak of 17% in 2023 and sustained growth at 15% in 2022, compared to a moderate presence of 3% in 2014. This upward trend reflects an increased awareness of the importance of optimizing the interaction between humans and vehicles, responding to the complex challenges of recent years' mobility and users' expectations for safety, comfort, and efficiency.

The evolution of research in automotive ergonomics (Figure 4f) is characterized by an evolutionary trajectory in which academic activity has shown fluctuating dynamics, with increased interest observable in recent years. In 2023, there is a notable rise, signifying a growing recognition of ergonomics as a key element in vehicle design. This can be

attributed to the automotive industry's increased attention to user safety, comfort, and efficiency. In contrast, the pre-2010 period reflects a more tempered approach to ergonomic research, with a relatively low number of academic contributions. However, the sustained growth trend after this period suggests a progressively important role in optimizing user interfaces and adapting vehicles to human factors needs in the context of technological advancements and emerging ecological and social requirements.

The study approach of ergonomics and comfort (Figure 4d,f,g) within vehicles has seen significant expansion due to the intensification of academic research reflected in the increasing percentage of publications from 3% in 2014 to a peak of 10% in 2023. The conceptual framework underlying both ergonomics and comfort highlights the recognition of their interdependence in creating an optimal user experience in vehicles. Although often studied separately due to their distinct specificities—ergonomics focusing on optimizing human interaction with various vehicle components and comfort addressing the subjective perceptions of occupants—these fields converge to improve passenger functionality and experiences. Recent trends indicate a greater integration effort in research, recognizing that combined attention to ergonomics and comfort can lead to significant innovations in vehicle design and improve safety and user satisfaction standards.

Analyzing the presented data, there is an increasing trend in research on ergonomics, comfort, and human factors engineering (Figure 4a–g) applied to vehicles, with particular emphasis in recent years. A peak interest in 2023, with 14% of the total analyzed publications, indicates heightened interest and focus on innovations and optimizations in these fields. The year 2024, with 4% of the total publications, suggests that interest in the field remains significant, although this figure may only partially reflect the year's research activity. The intermittency observed in the number of publications from previous years may reflect fluctuations in research funding allocation, changes in technological trends, and adaptation to market demands. However, since the early 2010s, there has been a general upward trend, except for 2016, which shows a temporary decrease in interest. These data may indicate that ergonomic comfort research in vehicles aligns with technological evolution and changing societal requirements, stimulated by the development of emerging automotive technologies such as autonomous vehicles.

The analysis of publications suggests that there is growing recognition of the importance of an integrated approach to ergonomics, comfort, and human factors engineering in vehicle design. Emerging trends indicate a strengthened synergy between these disciplines, suggesting a shift from treating them as disparate fields to an awareness that their interconnectedness can lead to significant industry innovations. This exhaustive approach is essential to meet the complex demands of modern users, who expect a high standard of performance, safety, and comfort from their vehicles. The increased interest reflected in recent publications may indicate a research focus on developing integrated solutions that address all aspects of the driving experience simultaneously.

The database was limited in the preliminary stage to 20,000 publications (according to Table 3 and Figure 5), from which only the following types of publications with an occurrence frequency ≤ 1 were selected: articles, conference papers, books, book chapters, and review articles.

The research methodology of the specialized literature includes analyses and investigations based on descriptive statistics (publication frequency, citation distribution), network analysis (co-citation and co-authorship), inferential statistics (hypothesis testing and linear regression to understand relationships between different bibliometric variables, such as the impact of external factors on the number of citations), long-term trends (cluster analysis: grouping works based on similarities in terms of topics or citations, and classification

techniques: identifying types of works or research trends using statistical or machine learning methods).

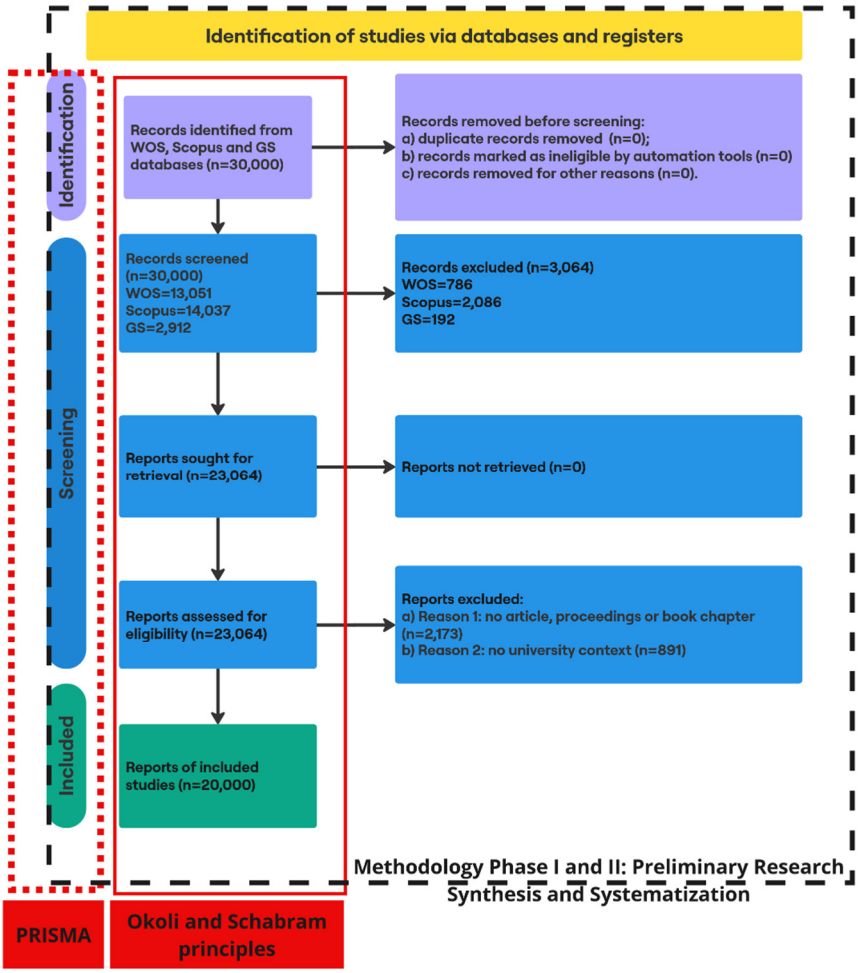


Figure 5. Research methodology. Phase I and phase II: Preliminary research and systematization and synthesis of specialized literature for the analyzed groups.

The specialized literature regarding the application of ergonomics in the automotive industry (Group 1—Table 3) was disseminated into 45% articles (73 publications), 18% conference papers (29 publications), 24% books (39 publications), 6% book chapters (9 publications), and 12% review articles (12 publications). For the next analyzed group (Group 2—Table 3), human factors engineering in vehicles, the bibliography was represented by: 78% articles (2013 publications), 15% conference papers (376 publications), 5% books (127 publications), and 3% book chapters (65 publications). Group 3—Comfort: 58% articles (3476 publications), 30% conference papers (1808 publications), 7% books (417), 3% book chapters (167), and 3% review articles (157). Group 4—Comfort-Ergonomics: 43% articles (74 publications), 18% conference papers (31 publications), 16% books (27), 3% book chapters (12), and 3% review articles (27). Group 5—Ergonomics-Human Factors Engineering: 53% articles (63), 20% conference papers (24), 10% books (12), 9% book chapters (11), and 8% review articles (10). Group 6—Comfort-Human Factors Engineering: 61% articles (1264), 18% conference papers (376), 12% books (243), 6% book chapters (127), and 3% review articles (65). Group 7—Comfort-Human Factors Engineering-Ergonomics: 53% articles (62), 20% conference papers (24), 10% books (12), 9% book chapters (11), and 8% review articles (9). Group 8—Thermal Comfort: 55% articles (710), 16% conference papers (203), 9% books (114), 4% book chapters (48), and 17% review articles (226). Group 9—Vibrational Comfort:

57% articles (231), 24% conference papers (97), 7% books (27), 2% book chapters (8), and 11% review articles (43). Group 10—Acoustic Comfort: 58% articles (3476), 30% conference papers (1808), 3% books (167), 3% book chapters (157), and 7% review articles (417). Group 11—Vibrational, Thermal, and Acoustic Comfort: 47% articles (54), 12% conference papers (14), 17% books (19), 3% book chapters (4), and 21% review articles (24). The graphical representation of the obtained data is systematized in Figure 6.

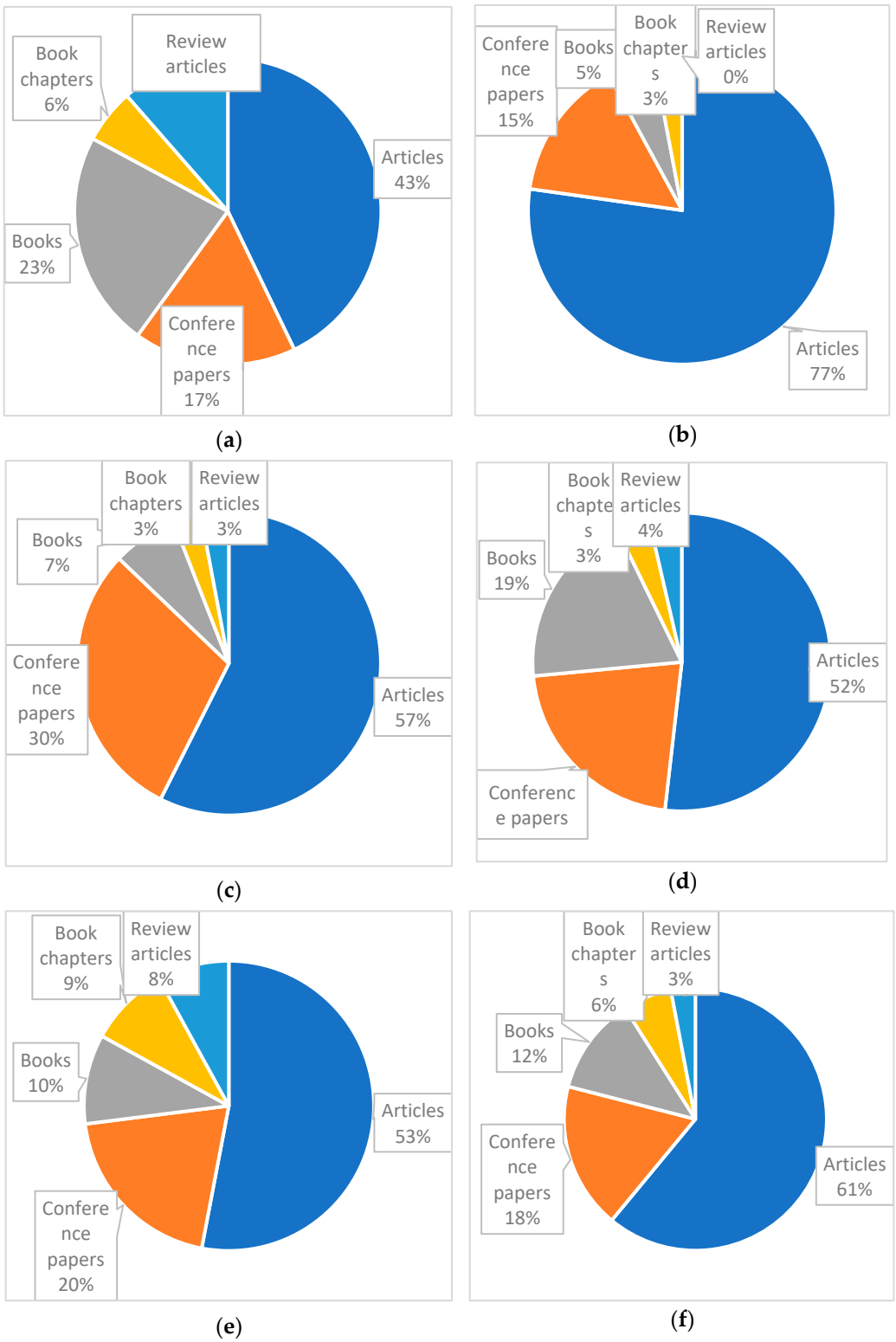


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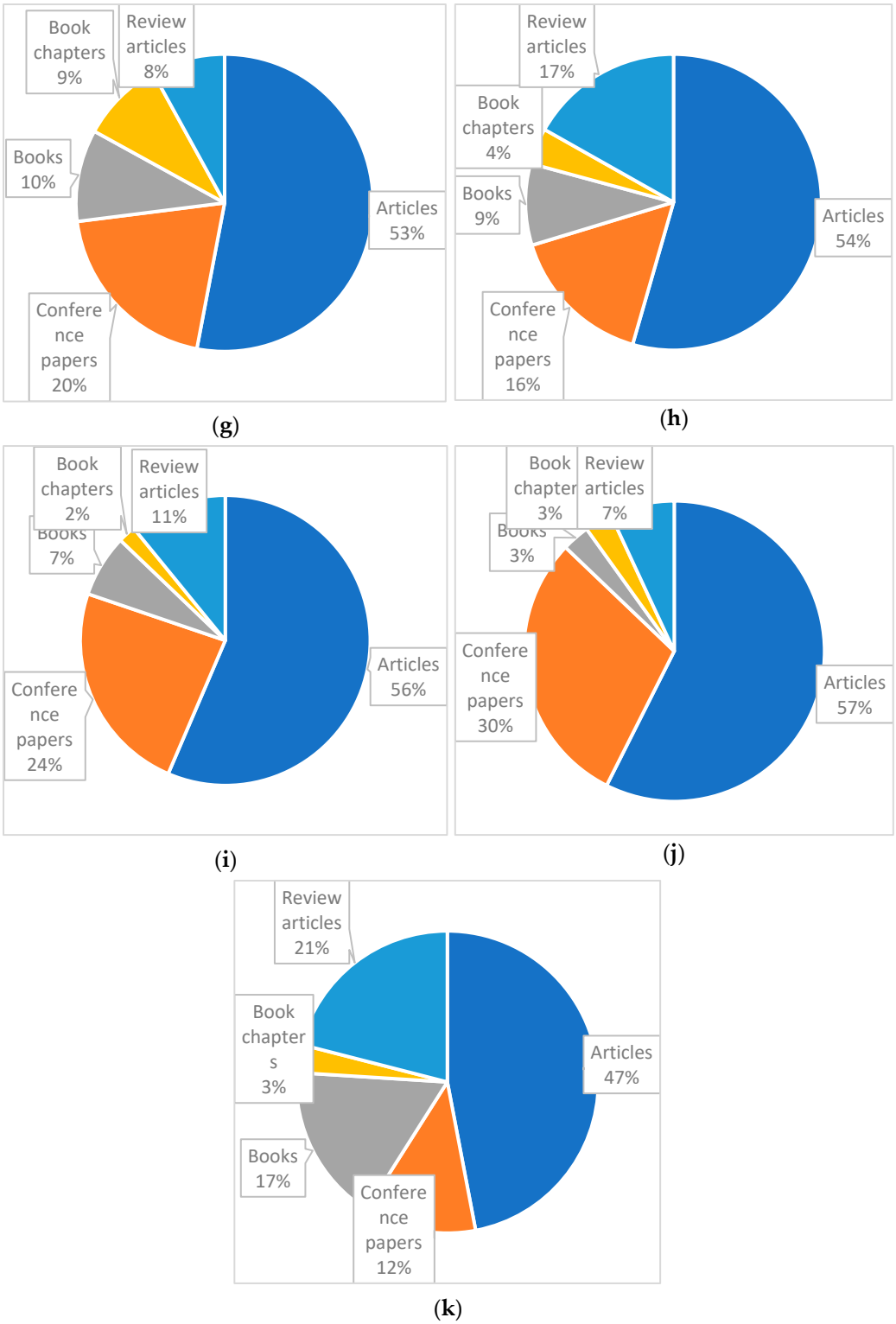


Figure 6. Distribution of publication types across reference groups in automotive ergonomics literature. (**a**) Ergonomics. (**b**) Human Factors Engineering. (**c**) Comfort. (**d**) Ergonomics and Comfort. (**e**) Ergonomics and Human Factors Engineering. (**f**) Comfort and Human Factors Engineering. (**g**) Comfort, Ergonomics and Human Factors Engineering. (**h**) Thermal Comfort. (**i**) Vibrational Comfort. (**j**) Acoustic Comfort. (**k**) Acoustic, Vibrational, and Thermal Comfort.

Citation analysis was conducted through database evaluation using VOSViewer Version 1.6.20, with a minimum threshold value of zero. The purpose of considering the minimum threshold value of zero was to exhaustively evaluate ergonomics, comfort, and

human factors engineering with applicability in transportation systems by considering all sources from the database. Tables 4–7 present the results of an analysis of sources based on the number of citations.

Table 4. List of the most cited publications regarding the application of ergonomics in CTS and MTS. Source: Scopus, Web of Science.

Author	Year	Publication and Innovation	Analyzed Group	No. of Citations	Reference
Pope et al.	2002	Spine ergonomics–Ergonomic solutions for preventing lower back pain in car seats	1	179	[52]
Flemisch et al.	2014	Towards cooperative guidance and control of highly automated vehicles: H-Mode and Conduct-by-Wire–Ergonomic concepts for the cooperative control of autonomous vehicles using two innovative concepts: "Conduct-by-Wire" and "H-Mode"	1	116	[53]
Andreoni et al.	2002	Method for the analysis of posture and interface pressure of car drivers—Innovation in the ergonomic design of car interiors by introducing a multifactorial method for analyzing the posture of drivers	1	108	[54]
Bovenzi et al.	2006	An epidemiological study of low back pain in professional drivers—Investigation of the prevalence of lower back pain among professional drivers exposed to whole-body vibrations and ergonomic risk factors, highlighting the relationship between vibration exposure and back pain intensity	1	93	[55]
Shamir	2004	How should an autonomous vehicle overtake a slower moving vehicle: Design and analysis of an optimal trajectory—A simplified mathematical model for overtaking trajectory, optimizing kinetic energy, to improve the ergonomic performance of autonomous vehicles.	1	88	[56]

Table 5. List of the most cited publications regarding the application of human factors engineering in CTS and MTS. Source: Scopus, Web of Science.

Author	Year	Publication and Innovation	Analyzed Group	No. of Citations	Reference
Miotto et al.	2018	Deep learning for healthcare: review, opportunities and challenges—Using deep learning technologies to transform health monitoring of passengers in vehicles	2	1033	[57]
Hodge et al.	2015	Wireless Sensor Networks for Condition Monitoring in the Railway Industry: A Survey—Using sensor-based technologies, especially wireless sensor networks (WSN), to automatically detect faults, reducing the need for human inspection and improving the safety and reliability of railway transport networks.	2	308	[58]

Table 5. *Cont.*

Author	Year	Publication and Innovation	Analyzed Group	No. of Citations	Reference
Plöchl et al.	2007	Driver models in automobile dynamics application—Integrating technologies to improve the human–vehicle interface, analyze driver behavior, and adapt vehicle design	2	202	[59]
Melcher et al.	2015	Take-Over Requests for automated driving—Strategies for designing systems for transition between automated and manual driving in vehicles	2	110	[60]
Lv et al.	2018	Analysis of Autopilot Disengagements Occurring During Autonomous Vehicle Testing—Investigating the circumstances and causes that lead to human intervention in the autopilot system (mechanisms and duration of transition from automated to manual control and optimization of automation technologies)	2	81	[61]

Table 6. List of the most cited publications regarding comfort assurance in CTS and MTS. Source: Scopus, Web of Science.

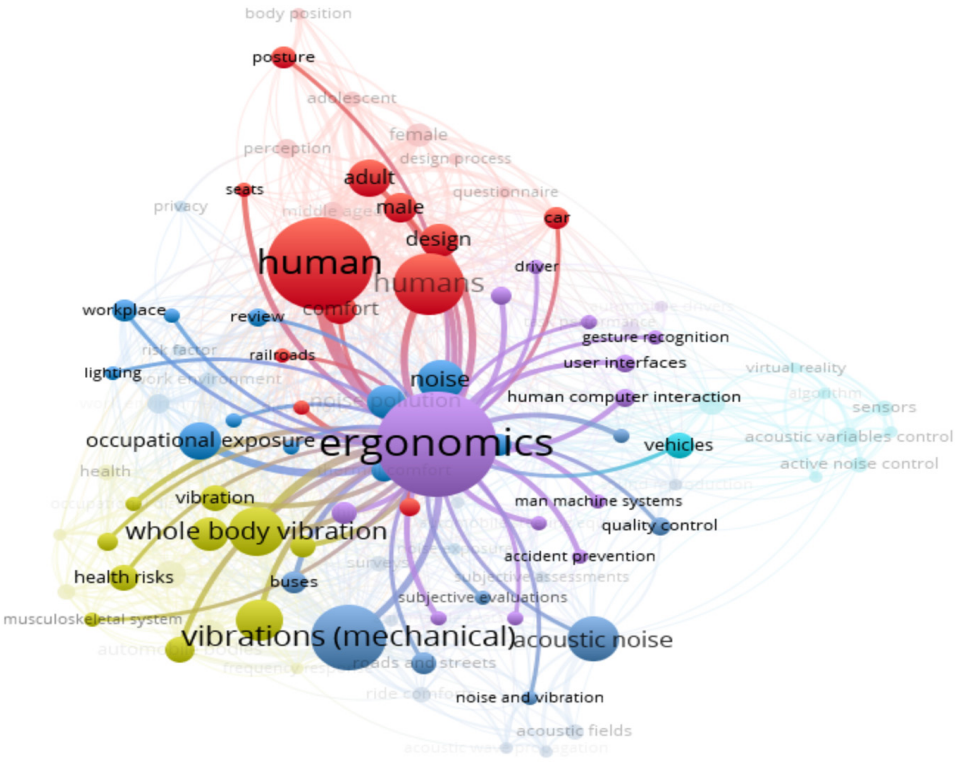
Author	Year	Publication and Innovation	Analyzed Group	No. of Citations	Reference
Sun et al.	2011	*Finite Frequency H_∞ Control for Vehicle Active Suspension Systems*—An innovative control method for vehicle active suspension systems to improve comfort (H-infinity in the finite frequency domain and KYP lemma, reducing disturbances within a certain frequency range)	3	345	[62]
Levinson et al.	2011	*Towards Fully Autonomous Driving: Systems and Algorithms*—Innovative algorithms and technologies for ensuring comfort in autonomous vehicles.	3	798	[63]
Li et al.	2011	*Model Predictive Multi-Objective Vehicular Adaptive Cruise Control*—An innovative adaptive cruise control system (ACC) in vehicles to improve driving comfort	3	419	[64]
Sun et al.	2013	*Saturated Adaptive Robust Control for Active Suspension Systems*—An innovative strategy for robust adaptive control for vehicle active suspension systems to improve ride comfort	3	333	[65]
Nguyen et al.	2014	*Joint Optimization of Electric Vehicle and Home Energy Scheduling Considering User Comfort Preference*—Innovative techniques for exploiting electric vehicles as dynamic storage facilities and detailed modeling of comfort preferences	3	200	[66]

Table 7. List of the most cited publications regarding the application of ergonomics, human factors engineering, and comfort in CTS and MTS. Source: Scopus, Web of Science.

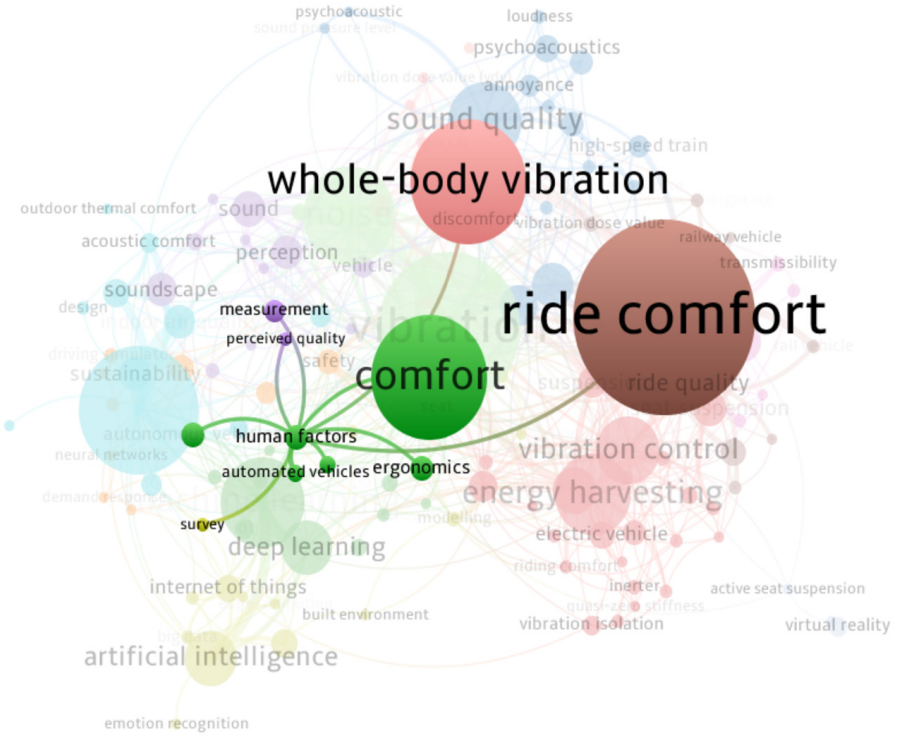
Author	Year	Publication and Innovation	Analyzed Group	No. of Citations	Reference
Duffy et al.	2015	*Handbook of Digital Human Modeling: Research for Applied Ergonomics and Human Factors Engineering– Using advanced technologies to ensure comfort*	6	249	[67]
Sekulić et al.	2016	*Definition and determination of the bus oscillatory comfort zones*—Using DOE (Design of Experiments) method and introducing a new concept of oscillatory comfort zones	6	33	[68]
Tiemessen et al.	2007	*An overview of strategies to reduce whole-body vibration exposure on drivers: A systematic review*—Innovative strategies to reduce vibration exposure for drivers (design and ergonomics factors and evaluation of driver behavior)	6	112	[69]
Caffaro et al.	2016	*Ergonomic analysis of the effects of a telehandler's active suspended cab on whole body vibration level and operator comfort*—Developing an active suspension system for the cab mounted on a telehandler to reduce WBV exposure and improve comfort based on user experience	6	47	[70]
Petersen et al.	2007	*A moving zone of quiet for narrowband noise in a one-dimensional duct using virtual sensing*—Virtual method for active noise control adapted to follow the ears of the observer	6	38	[71]

A bibliometric analysis was conducted to investigate the key terms of the most cited papers according to group (all 10 groups were analyzed—Table 3). The results are systematically represented in Figures 7 and 8. A minimum of 10 keyword occurrences were considered for the current analysis to map all keywords from the specialized literature regarding ergonomics, human factors engineering, and comfort, with the three dimensions: thermal, vibrational, and acoustic, applied to vehicles. For Reference Group 1 (Figure 7a)—the total number of keywords reached 8853, with only 3826 words meeting the preliminary selection criteria. All selected keywords were represented in five groups with 247 links and a total link strength of 141,537. For Reference Group 2 (Figure 7b)—the total number of keywords reached 29,444, with only 7841 words meeting the preliminary selection criteria. All selected keywords were represented in nine groups with 112 links and a total link strength of 3778. For Reference Group 3 (Figure 7c)—the total number of keywords reached 21,675, with only 7246 words meeting the preliminary selection criteria. All selected keywords were represented in nine groups with 157 links and a total link strength of 6340. The size of the node is proportional to the number of occurrences (frequency) and the link strength of a keyword in the analyzed database.

The analysis of contributing countries for the collected sources is represented in Figure 9. The co-citation analysis of countries (Figure 10) identifies the nations that have contributed to the research in the referenced domains analyzed. The size of the nodes is proportional to the number of publications, and the thickness of the line connecting the countries represents the strength of research collaboration.

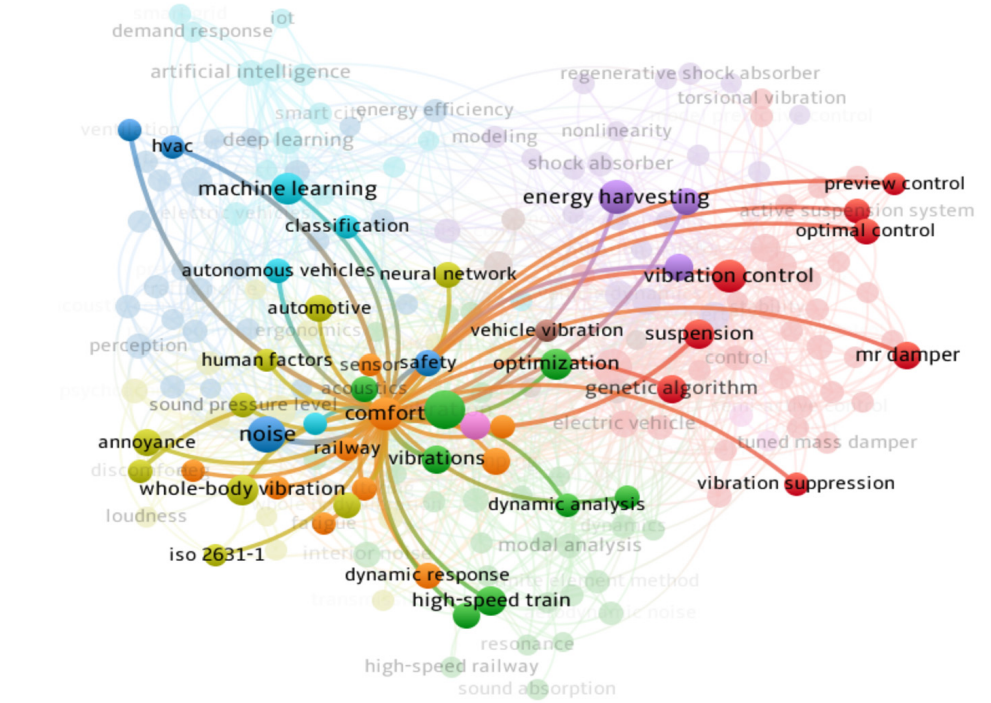


(**a**)

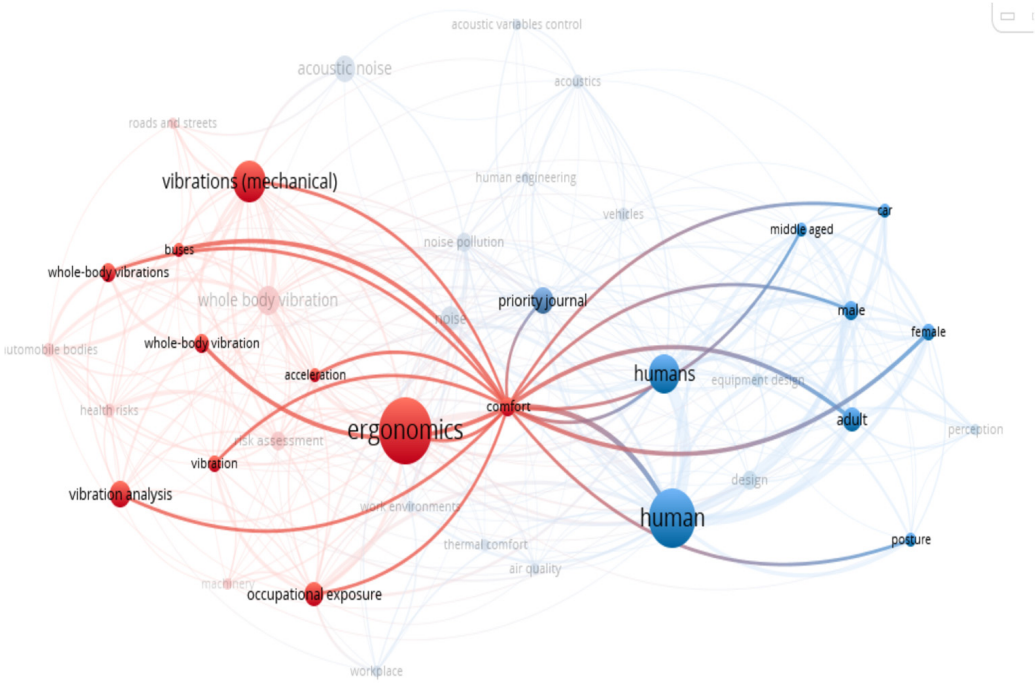


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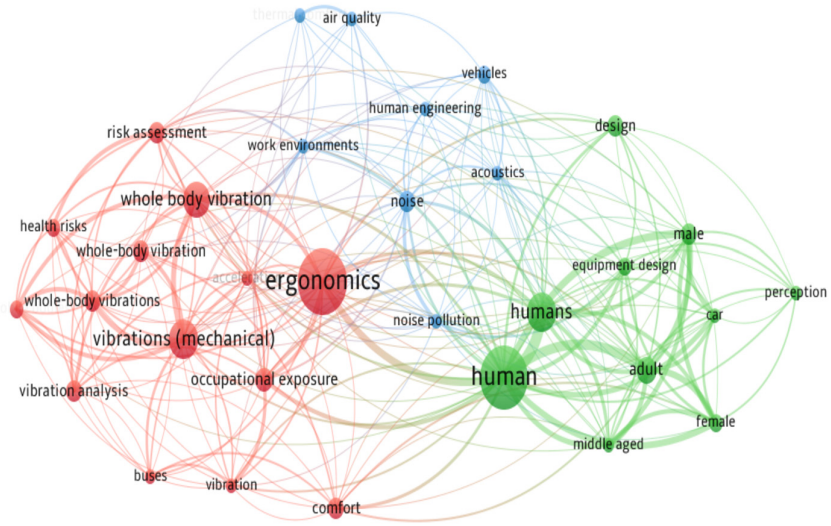


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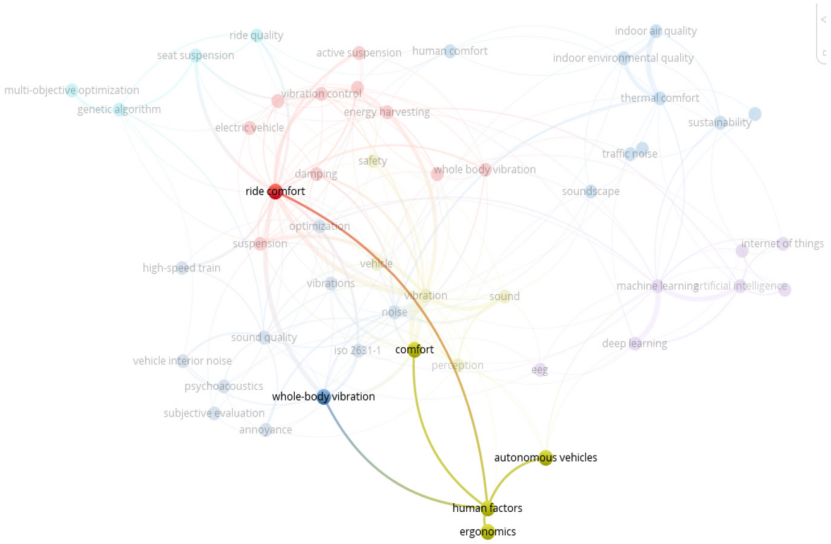


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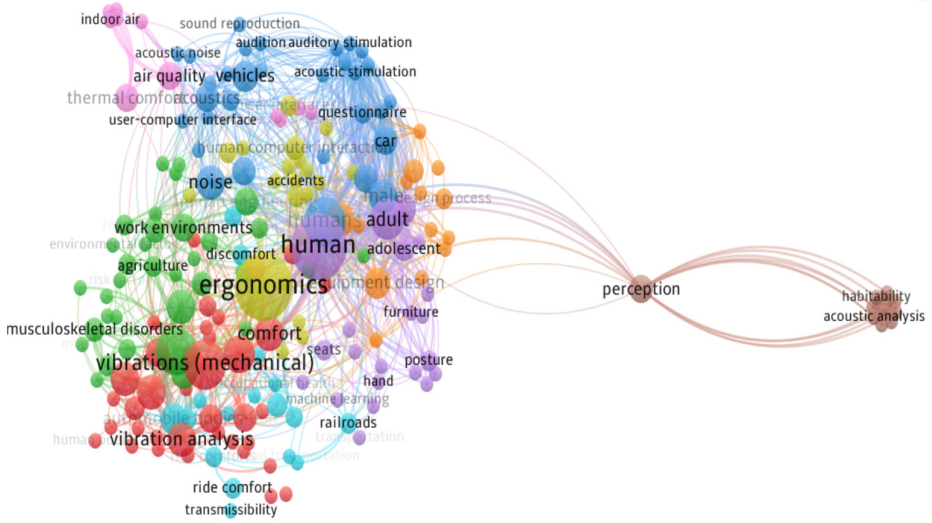
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(**e**)



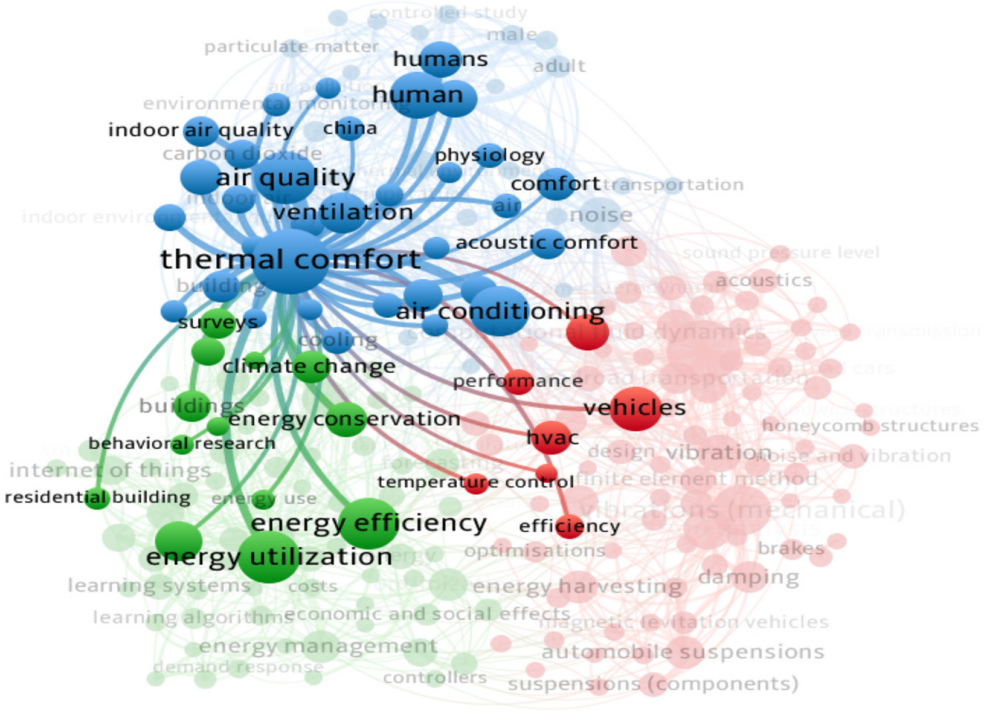
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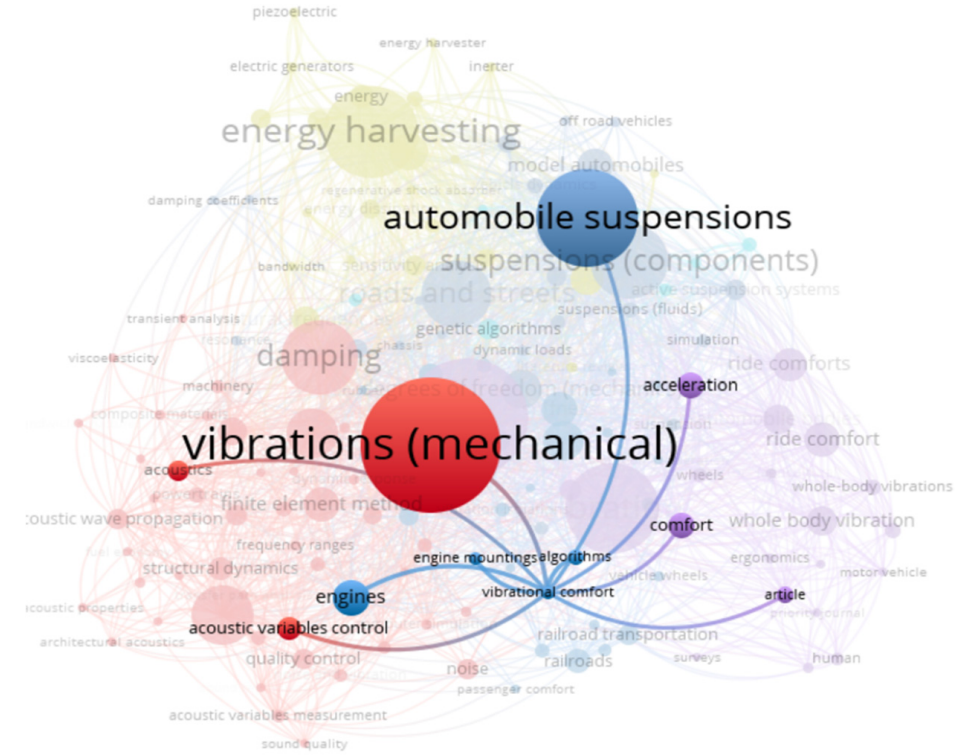
(**g**)

Figure 7. Bibliometric analysis of keywords and most cited authors for research groups. Source: Scopus, Web of Science. (**a**) Ergonomics. (**b**) Human Engineering. (**c**) Comfort. (**d**) Ergonomic–Comfort. (**e**) Ergonomic–Human Engineering. (**f**) Human Engineering–Comfort. (**g**) Human Engineering–Comfort–Ergonomics.

In this research, the co-citation network analysis of cited authors using the VOSviewer application covered 6159 authors. The minimum citation threshold for an author was set at 20 citations. The reference publications involved contributions from 204 countries in comfort research, 182 countries in human factors engineering, and 93 countries in ergonomics.



(**a**)



(**b**)

Figure 8. *Cont.*

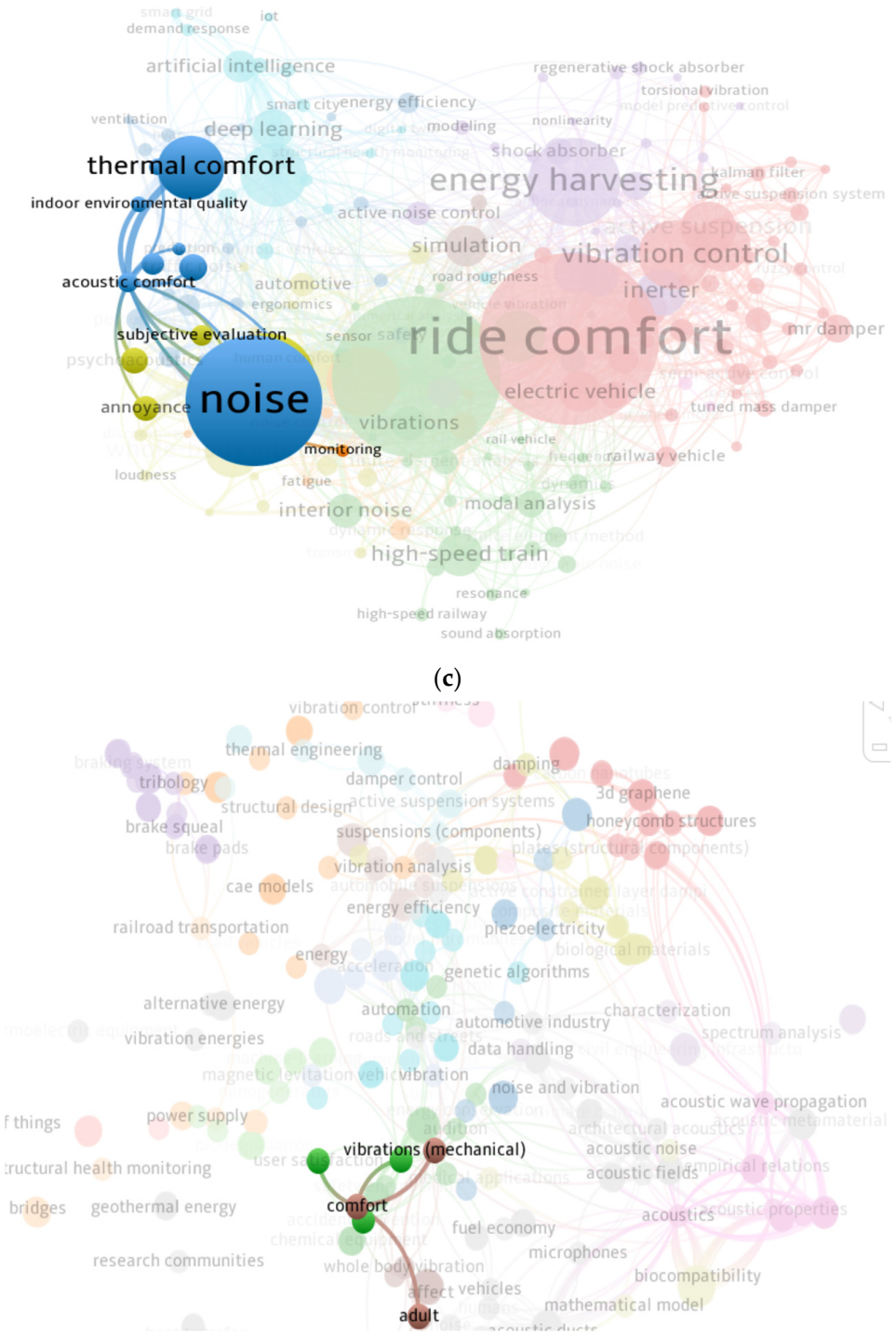
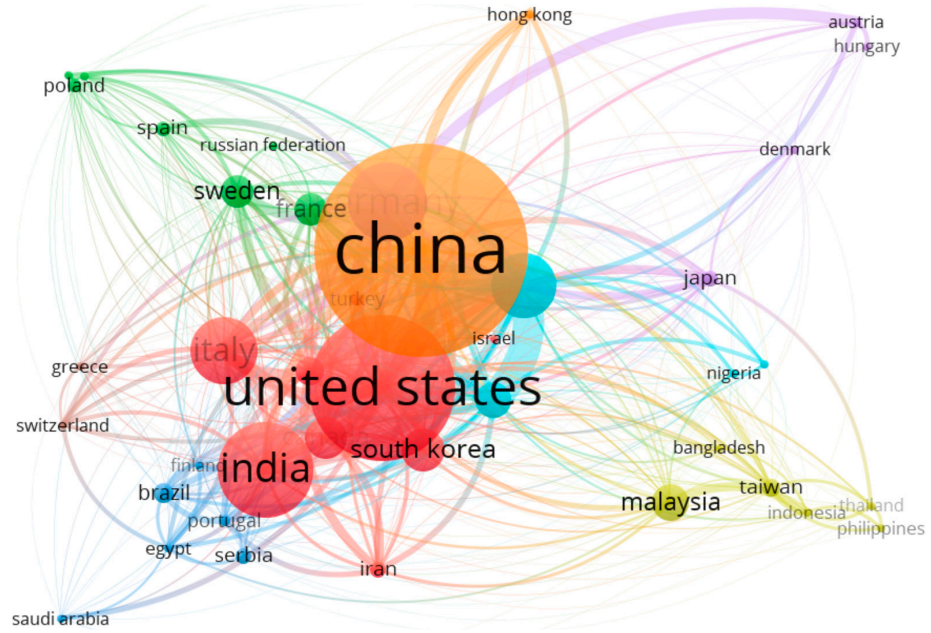


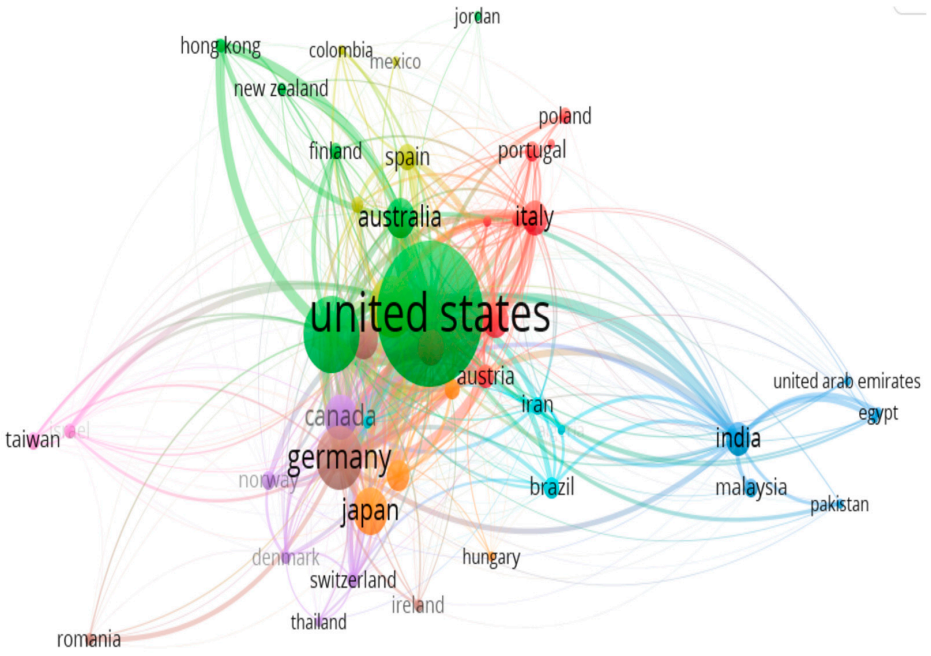
Figure 8. Bibliometric analysis of keywords and top cited authors for research on thermal, vibrational, and acoustic comfort in vehicles. Source: Scopus, Web of Science. (**a**) Thermal comfort. (**b**) Vibrational comfort. (**c**) Acoustic comfort. (**d**) Thermal, Vibrational, and Acoustic comfort.

For Group 1 (Figures 9a and 10)—the collection of sources on ergonomics applied to vehicles—the results regarding the contributing countries to research were as follows: China: 17% (255 publications), India: 12% (175 publications), Germany: 6% (95 publications), Italy: 5% (81 publications), United Kingdom: 5% (78 publications), South Korea, Canada, Malaysia, Australia, Sweden, France: 3% (52, 51, 45, 43, 40, 39 publications), Netherlands and Brazil: 2% (35 and 25 publications); along with 62 other countries with percentages $\leq$ 1%, including Romania with 4 publications. For Group

2 (Figures 9b and 10)—Human Factors Engineering: United States: 33% (1498 publications), China: 10% (438 publications), Germany: 7% (300 publications), United Kingdom: 6% (293 publications), Japan: 4% (171 publications), Canada and Australia: 3% (155 and 119 publications), Sweden, Netherlands, France, Italy, India, South Korea: 2% (115, 104, 100, 95, 85, 76 publications); along with 74 other countries with percentages $\leq$ 1%, including Romania with 14 publications. For Group 3—Comfort (Figures 9c and 10): China: 29% (255 publications), United States: 8% (387 publications), India: 6% (287 publications), Germany: 6% (282 publications), Japan: 5% (246 publications), United Kingdom: 4% (172 publications), South Korea, Italy, France: 3% (150, 149, 122 publications), Malaysia, Australia, Iran, Turkey, Canada, Spain: 2% (93, 76, 76, 75, 73, 73 publications); along with 66 other countries with percentages $\leq$ 1%, including Romania with 63 publications.

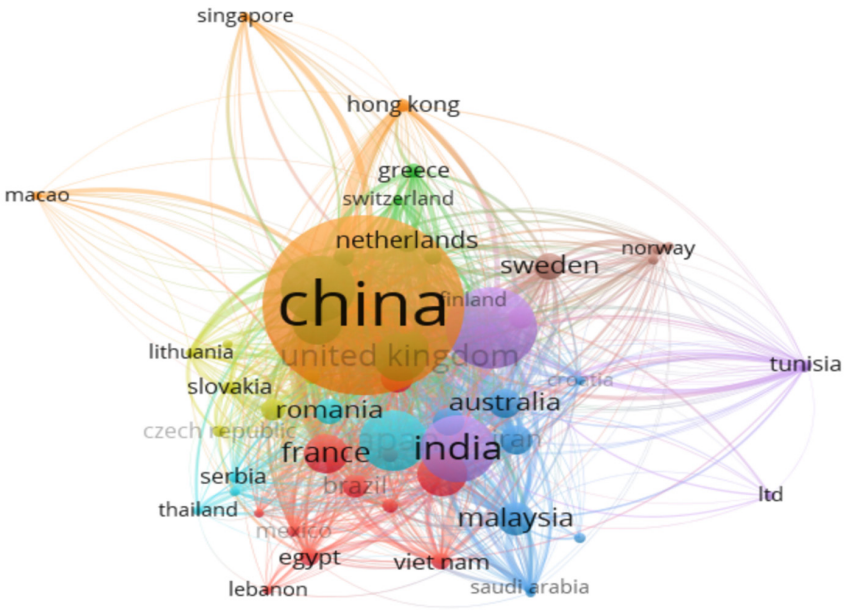


(**a**)



(**b**)

Figure 9. *Cont.*



(**c**)

Figure 9. Bibliometric analysis of contributing countries for research on comfort, ergonomics, and human factors engineering in vehicles. Source: Scopus, Web of Science. (**a**) Group 1 Analysis. (**b**) Group 2 Analysis. (**c**) Group 3 Analysis.

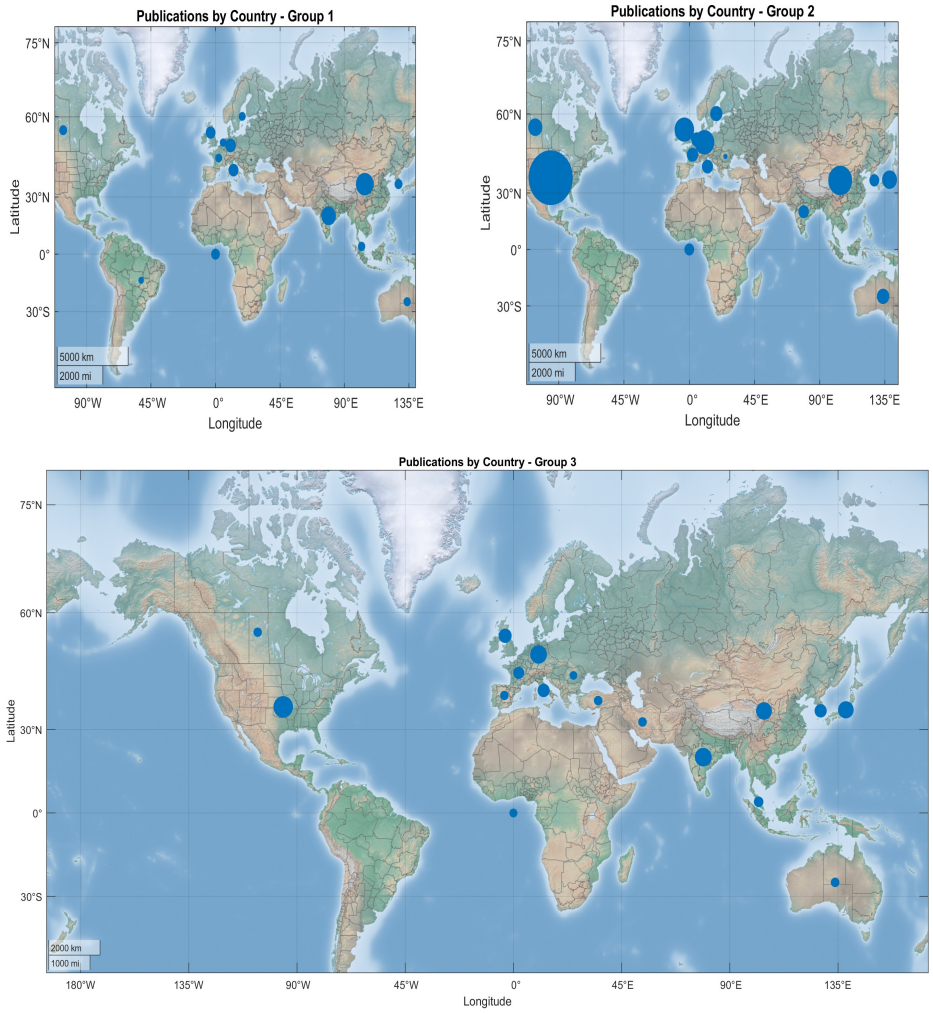


Figure 10. Geographical distribution of publications by country for research groups.

The systematic approach has demonstrated the importance of using scientometric methods to investigate comfort research and an integrated manner of complementary fields—ergonomics and human factors engineering, with applicability in transportation systems, particularly in the automotive industry. Moreover, no other exhaustive and integrated bibliometric review of the literature in this field of comfort research has been conducted from 1950 to April 2024. There is a significant increase in interest in these fields, with a remarkable peak of 17% in research in 2023 and continued stable interest in 2024, with a percentage of 4% of the total publications, which suggests an increased focus on innovation and optimization in vehicle design to meet user expectations regarding safety, comfort, and efficiency. Over 30,000 relevant publications were analyzed. Most of the publications were identified on Google Scholar. For automotive ergonomics research, 148 publications were identified in Scopus and 372 in Web of Science. For human factors engineering: 2082 publications in Scopus and 1894 on the Web of Science. For comfort: 6060 publications in Scopus and 9784 in Web of Science.

The demonstrated systematic and scientometric approach highlights a well-defined methodology and an objective strategy for collecting and analyzing relevant data, minimizing systematic errors, and providing a solid basis for research results. The use of network analysis, descriptive statistics, and inferential investigations shows an effective integration of various bibliometric methods to offer a broad perspective on the field studied.

The importance of an integrated approach to ergonomics, human factors engineering, and comfort is highlighted, indicating a transition from treating these as disparate fields to recognizing the synergy between them to develop innovation in the automotive industry. The increase in the number of publications and growing interest in research reflects the recognition of the importance of these fields in improving the user experience of vehicles.

These studies make significant contributions to the field of comfort, offering a comprehensive perspective on the relationship between comfort, ergonomics, and human factors engineering in the automotive industry, and providing relevant information on the strategies pursued over time to ensure these goals, as well as the current research directions.

The ergonomic principles and human factors engineering methodologies explored in this study are applicable beyond transportation, offering significant insights for sectors such as autonomous systems, wearable technology, and defense safety.

6. Conclusions

The demonstrated systematic and scientometric approach highlights a well-defined methodology and an objective strategy for collecting and analyzing relevant data, minimizing systematic errors, and providing a solid basis for research results. The use of network analysis, descriptive statistics, and inferential investigations shows an effective integration of various bibliometric methods to offer a broad perspective on the field studied.

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These studies make significant contributions to the field of comfort, offering a comprehensive perspective on the relationship between comfort, ergonomics, and human factors engineering in the automotive industry, and providing relevant information on the strategies pursued over time to ensure these goals, as well as the current research directions.

This research provides an integrated perspective on the application of ergonomics and human factors engineering to improve comfort and efficiency in MTS and CTS, identified as imperative research needs. This is since comfort has become the definition of vehicle

quality in CTS, and in MTS, comfort directly influences crew performance in the operational environment. Additionally, protecting their health is vital. The study highlighted the importance of adopting an integrative and scientifically grounded approach, which adds value by eliminating systematic errors to meet user needs and ensure the optimal performance of vehicles in diverse operational environments.

The novelty of this study lies in the hybrid use of bibliometric methods and case studies to identify and analyze the main characteristics and trends in research on ergonomics and human factors engineering to promote efficiency, comfort, and performance in operational environments. The results of this scientific endeavor have confirmed the research hypotheses and demonstrated that ergonomic principles and human factors engineering can significantly contribute to improving the comfort, safety, and performance of vehicle users in both civilian and military contexts.

The findings of this study offer practical value for enhancing transport system design. In civilian transport, ergonomic principles can guide the creation of user-friendly vehicle interiors, such as adjustable car seats or intuitive control interfaces that minimize distraction. For military transport, vibration-dampening technologies and optimized control layouts can reduce crew fatigue and improve operational efficiency. Moreover, integrating AI-driven adaptive systems allows for real-time adjustments to user needs, enhancing both comfort and safety. These applications demonstrate the potential of ergonomic design to meet diverse operational and user demands.

Based on the findings of this study, the following future research directions are proposed: Investigating how new technologies, such as autonomous and connected vehicles, influence human–machine interaction and require advanced ergonomic solutions; exploring the use of artificial intelligence to create smarter and more responsive transportation systems that optimize user comfort and performance; extending research to include diverse user groups, such as the elderly and individuals with disabilities, to ensure inclusive and accessible design; continuing the development of specific ergonomic solutions for military vehicles, considering the unique requirements and challenges in this field.

By integrating ergonomic and cognitive engineering principles across both civilian and military domains, this study lays the groundwork for future interdisciplinary collaborations aimed at improving human–vehicle interaction and operational efficiency.

In conclusion, this study underscores the importance of an integrated approach to improving human–machine interactions and developing vehicles that meet modern users' expectations regarding safety, comfort, and efficiency. The findings and proposed future research directions provide a valuable framework for future innovations in civilian and military transportation.

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