ERGONOMIC COMPATIBILITY AS AN ESSENTIAL ELEMENT OF OCCUPATIONAL SAFETY

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Abstract: Ergonomic compatibility is a fundamental condition for establishing safe, healthy, and sustainable working environments. The effectiveness of occupational safety measures depends not only on technical protection and compliance with regulatory requirements but also on how appropriately work activities, equipment, and environmental conditions correspond to the physical and cognitive capabilities of employees. A mismatch between human capabilities and workplace demands may contribute to excessive physical strain, repetitive movements, awkward postures, fatigue, reduced attention, and work-related errors. This article examines ergonomic compatibility as an integrated element of occupational safety management. The study considers anthropometric, biomechanical, physiological, cognitive, psychosocial, and environmental factors influencing the interaction between workers and production systems. Particular attention is given to the limitations of workplace improvements that address individual ergonomic problems without examining the entire work system. An original six-dimensional ergonomic compatibility model is proposed, connecting human characteristics, work tasks, equipment, workspace, environmental conditions, and work organization. A conceptual Ergonomic Compatibility Index (ECI) is developed to support the systematic assessment of workplace suitability. The proposed methodology emphasizes that ergonomic improvement should begin with the identification of mismatches between worker capabilities and occupational demands, followed by the selection of appropriate technical, organizational, and preventive measures. The findings provide a methodological basis for integrating ergonomic assessment into occupational safety management and workplace design.

Keywords: ergonomic compatibility, occupational safety, workplace design, human factors, anthropometry, biomechanical load, musculoskeletal disorders, work environment, ergonomic risk assessment, human-centred design

Introduction

The development of modern production systems has significantly changed the relationship between workers, technological equipment, and the working environment. Mechanization and automation have reduced certain forms of physical labour, but they have also introduced new demands associated with continuous monitoring, repetitive operations, prolonged sitting, intensive information processing, and interaction with complex technical systems. As a result, occupational safety increasingly depends on the degree to which the working environment corresponds to human capabilities and limitations.

One of the central problems in this context is the mismatch between the characteristics of a worker and the requirements imposed by the workplace. Such incompatibility may occur when a workstation is designed without considering anthropometric differences, when equipment requires excessive physical effort, when tools are unsuitable for the task, or when environmental conditions interfere with concentration and performance.

These problems are not always immediately visible. Unlike an exposed electrical conductor or an unguarded machine component, an ergonomically unsuitable workplace may not produce an immediate accident. Its negative effects can develop gradually through repeated physical loading,

prolonged uncomfortable postures, excessive mental effort, or insufficient recovery time. Over time, these conditions may contribute to work-related musculoskeletal disorders, fatigue, reduced work capacity, and an increased probability of operational errors.

The International Organization for Standardization, through ISO 6385:2016, establishes fundamental ergonomic principles for the design of work systems. The standard emphasizes the need to consider the interactions between workers, equipment, workspace, tasks, and the working environment throughout the design and operational life cycle of a work system [1].

The International Labour Organization also considers ergonomics a multidisciplinary field concerned with optimizing the interaction between people and other elements of a work system. Its approach includes physical, cognitive, and organizational factors rather than limiting ergonomic assessment to posture or manual handling [2].

Despite the availability of these principles, ergonomic improvements in many workplaces are still implemented as isolated measures. For example, an enterprise may replace an uncomfortable chair without examining the height of the work surface, the position of the display, lighting conditions, or the duration of uninterrupted work. Similarly, introducing mechanical lifting equipment may reduce manual handling but create new requirements for operator visibility, access, and control.

This demonstrates that ergonomic compatibility cannot be achieved by correcting a single workplace element while ignoring the remaining components of the work system.

The scientific problem addressed in this article is the insufficient integration of human characteristics, occupational task requirements, technical equipment, and environmental conditions into a unified framework for evaluating ergonomic compatibility as part of occupational safety management.

The purpose of the research is to develop a methodological approach for assessing and improving ergonomic compatibility between workers and production systems, with particular attention to the prevention of excessive physical and cognitive workload.

The research objectives are:

1. To identify the principal factors determining ergonomic compatibility in occupational activities.
2. To examine the relationship between workplace design and occupational safety.
3. To analyse the consequences of incompatibility between human capabilities and work demands.
4. To develop an integrated model for evaluating ergonomic compatibility.
5. To propose a methodological indicator for identifying and comparing ergonomic deficiencies.
6. To formulate practical measures for incorporating ergonomic assessment into occupational safety management.

The scientific contribution of the study is the development of a six-dimensional ergonomic compatibility model and a corresponding conceptual assessment index that considers the interaction of human, technical, spatial, environmental, and organizational factors.

Materials and Methods

The study applies a theoretical and analytical research approach based on ergonomic principles, occupational safety management, human factors analysis, and workplace design.

The methodological framework consists of four main procedures.

Systems analysis is used to examine the workplace as an interconnected system in which human characteristics, equipment, tasks, environmental conditions, and organizational arrangements influence one another.

Functional analysis is applied to identify the physical and cognitive requirements associated with different occupational activities. These requirements include force exertion, repetitive movements, body positioning, visual attention, information processing, and decision-making.

Comparative analysis is used to distinguish between ergonomically compatible and incompatible workplace arrangements and to identify the potential consequences of their differences.

Conceptual modelling provides the basis for developing an integrated compatibility model and a quantitative assessment framework.

The study is theoretical and methodological in nature. It does not present experimental measurements or field survey results. The proposed model and assessment index are original methodological proposals that require practical testing and empirical validation.

For the purposes of this study, ergonomic compatibility is defined as:

The degree to which the physical, cognitive, and functional requirements of a work system correspond to the capabilities, characteristics, and limitations of the person performing the work.

This definition places emphasis on the relationship between human capabilities and workplace demands rather than on the isolated comfort of individual equipment components.

Ergonomic compatibility is achieved when the design of work activities, equipment, and environmental conditions allows employees to perform assigned tasks without unnecessary physical or cognitive strain.

It should be emphasized that ergonomic compatibility does not mean reducing every occupational task to the lowest possible level of effort. Certain professional activities inevitably require physical strength, concentration, and sustained attention. The objective is to ensure that such demands remain appropriate, manageable, and consistent with human capabilities.

The study identifies six dimensions that determine the compatibility of a workplace with the person performing the work.

Anthropometric compatibility concerns the relationship between workplace dimensions and the physical measurements of employees.

Relevant characteristics include body height, reach distance, sitting height, limb dimensions, shoulder breadth, and other body measurements that influence workplace interaction.

A workstation that is too high or too low may force employees to maintain uncomfortable body positions. Similarly, insufficient legroom or excessive reaching distances may create unnecessary physical strain.

Anthropometric design should therefore account for variation within the working population rather than relying on a single assumed body size.

Biomechanical compatibility refers to the relationship between the physical demands of a task and the capacity of the human musculoskeletal system.

The main factors include:

- Manual lifting and carrying;
- Pushing and pulling forces;
- Repetitive movements;
- Static muscular loading;
- Awkward body postures;
- Joint loading;
- Whole-body and hand-arm vibration.

When these demands are excessive or sustained for long periods, they may contribute to musculoskeletal discomfort and work-related disorders.

Physiological compatibility concerns the relationship between occupational workload and the functional capacity of the human body.

It includes energy expenditure, physical endurance, fatigue development, recovery opportunities, and the influence of temperature and other environmental conditions.

A task may be technically simple but physiologically demanding when it requires prolonged standing, continuous physical effort, or work under elevated temperatures.

Cognitive compatibility describes the relationship between information-processing requirements and the mental capabilities of employees.

Modern production systems frequently require workers to monitor displays, interpret warning signals, identify abnormal operating conditions, and make decisions within limited time.

Poorly organized interfaces, excessive information, unclear warning signals, and frequent interruptions may increase cognitive workload and contribute to errors.

This dimension concerns the influence of work organization and social conditions on employee well-being and performance.

Relevant factors include workload distribution, work schedules, autonomy, role clarity, management support, interpersonal relationships, and opportunities for recovery.

Even a physically well-designed workplace may remain ergonomically unsuitable if employees are exposed to excessive time pressure, insufficient breaks, or poorly organized responsibilities.

Environmental compatibility concerns the relationship between working conditions and human sensory and physiological requirements.

The principal factors include:

- Lighting and visual conditions;
- Noise exposure;
- Temperature and humidity;
- Air quality and ventilation;
- Workplace layout;
- Space availability;
- Vibration and other environmental influences.

These factors may affect both health and the accuracy with which occupational tasks are performed.

The assessment of ergonomic compatibility should begin with an examination of the actual work process.

The following sequence is proposed:

1. Identify the occupational task and its technological characteristics.
2. Determine the physical and cognitive demands imposed on the employee.
3. Examine workplace dimensions, equipment, and tool characteristics.
4. Evaluate environmental and organizational conditions.
5. Identify mismatches between human capabilities and workplace demands.
6. Select appropriate corrective measures.
7. Reassess the workplace after the improvements have been implemented.

This approach avoids the assumption that every ergonomic problem can be solved through equipment replacement alone.

For example, excessive shoulder loading may result from an inappropriate work surface, the location of materials, the frequency of repeated movements, or an unsuitable work sequence. Corrective measures should address the actual cause rather than only its visible manifestation.

Results

The analytical findings provide the basis for an integrated model consisting of six interconnected dimensions.

The model considers ergonomic compatibility as the outcome of interaction between the worker and the complete work system.

For instance, an employee may work at a suitable table height but still experience excessive strain because the task requires repetitive movements. Likewise, appropriate equipment may not produce the expected improvement if the surrounding space restricts movement.

Consequently, ergonomic assessment should examine the combined effect of all six dimensions.

Ergonomic incompatibility may influence occupational safety through several mechanisms.

The first mechanism is the development of excessive physical loading. Repeated movements, sustained awkward postures, and high-force activities may increase musculoskeletal demands.

The second mechanism is fatigue accumulation. When work intensity exceeds the available recovery opportunities, employees may experience reduced endurance and concentration.

The third mechanism is the deterioration of task performance. Poor visibility, inappropriate equipment arrangement, and excessive cognitive workload may interfere with the accurate execution of occupational procedures.

The fourth mechanism is the development of compensatory behaviour. When workplace arrangements are unsuitable, employees often adapt their movements or working methods to complete assigned tasks. Although such adaptations may appear effective in the short term, they can introduce additional risks.

For example, an employee may repeatedly bend the back because materials are stored below a suitable working height. Another worker may rotate the trunk frequently because the workstation does not provide adequate access to necessary tools.

These examples demonstrate that unsafe physical behaviour may originate from workplace design rather than from individual negligence.

Proposed Ergonomic Compatibility Index. To provide a systematic basis for evaluating workplace suitability, the study proposes the Ergonomic Compatibility Index (ECI).

The weighting coefficients should be established according to the nature of the occupational activity. For example, biomechanical compatibility may receive greater attention in manual material handling, whereas cognitive compatibility may be particularly important in control rooms and process-monitoring operations.

The index is not intended to replace specialized ergonomic risk assessment methods. Its purpose is to provide an integrated overview that can help identify which dimensions require further investigation.

A critical limitation must also be considered: a high overall index cannot compensate for a severe hazard in one particular dimension. Therefore, the assessment should include a separate review of critical risk factors, such as excessive manual handling, hazardous vibration, inadequate visibility, or unsafe machine access.

For preliminary methodological assessment, the following classification is proposed.

These categories are proposed for research and preliminary organizational assessment. They are not official ISO classifications or legally established certification levels. Their suitability must be determined through expert review and empirical testing.

Ergonomic assessment methods and their practical application

Different occupational activities require different assessment methods. A universal measurement technique cannot adequately evaluate every type of ergonomic exposure.

For example, RULA may be appropriate for examining upper-body postures, whereas the NIOSH Lifting Equation is specifically intended for evaluating certain manual lifting activities. Neither method independently provides a complete assessment of all ergonomic dimensions.

The proposed ECI can be used as an overall organizational framework, while specialized methods provide detailed information about particular hazards.

A systematic mechanism for improving ergonomic compatibility

Based on the proposed model, a seven-stage improvement mechanism is developed.

Stage 1. Workplace characterization

The organization identifies the occupational tasks, equipment, working positions, production sequence, and environmental conditions associated with a particular workplace.

Stage 2. Human capability analysis

The assessment examines relevant anthropometric, physical, sensory, and cognitive requirements. The objective is to understand the range of human characteristics that must be accommodated by the workplace.

Stage 3. Identification of ergonomic mismatches

The actual workplace conditions are compared with the demands imposed on employees. Particular attention is given to excessive force, repetitive activity, awkward postures, visual difficulties, and information-processing demands.

Stage 4. Risk prioritization

Identified problems are classified according to their severity, exposure frequency, duration, and potential consequences.

Stage 5. Selection of corrective measures

Measures are selected according to the hierarchy of practical interventions. Priority should generally be given to eliminating unnecessary demands and redesigning the work system before relying exclusively on individual protective or behavioural measures.

Stage 6. Implementation and employee participation

Corrective measures are introduced with the involvement of employees who perform the relevant tasks. Their practical experience can reveal problems that may not be apparent during a technical inspection.

Stage 7. Verification and continuous improvement

The workplace is reassessed after modifications. The organization examines whether physical and cognitive demands have been reduced and whether new problems have emerged.

This mechanism establishes ergonomic improvement as a continuous process rather than a one-time workplace adjustment.

Practical examples of ergonomic compatibility

The application of the model can be illustrated through several production situations.

When workers repeatedly lift and carry materials, ergonomic incompatibility may arise from excessive load weight, unsuitable lifting height, long carrying distances, or repeated trunk rotation.

Appropriate measures may include mechanical lifting equipment, improved storage arrangements, reduced carrying distances, and redesign of material flow.

An operator may experience discomfort when controls, displays, and frequently used tools are positioned outside convenient reach.

Workstation redesign should consider anthropometric variation, visual requirements, movement frequency, and the need to access emergency controls.

Prolonged computer use may involve sustained sitting, repetitive hand movements, unsuitable screen positioning, and insufficient visual recovery.

Ergonomic improvement may require adjustable furniture, suitable display positioning, appropriate lighting, task variation, and planned opportunities for movement.

Agricultural workers may be exposed to repetitive manual operations, prolonged bending, vibration from machinery, high temperatures, and physically demanding work schedules.

Ergonomic measures may include appropriate tool selection, mechanization of repetitive tasks, improved equipment adjustment, and work-rest arrangements suitable for the actual workload and environmental conditions.

These examples demonstrate that ergonomic compatibility must be adapted to the specific characteristics of each occupational sector.

Discussion

The proposed model highlights the importance of considering ergonomic compatibility as a preventive component of occupational safety rather than as a secondary issue related only to workplace comfort.

One of the main implications is that the design of work should begin with an understanding of human capabilities and the demands of the intended task. Adjusting the worker to an unsuitable system may produce temporary improvements, but it does not eliminate the underlying source of incompatibility.

This position is consistent with the systems approach established in ISO 6385:2016, which considers the interaction between workers, equipment, tasks, workspace, and the working environment [1].

Ergonomic compatibility and musculoskeletal health

Musculoskeletal disorders represent an important area of concern in occupational ergonomics. They may affect muscles, tendons, joints, nerves, and other structures involved in movement.

The U.S. National Institute for Occupational Safety and Health identifies excessive force, repetitive movements, awkward postures, and vibration among the factors associated with work-related musculoskeletal disorders [3].

The important methodological implication is that these factors should not be assessed separately when they occur simultaneously.

For example, repetitive work performed with a neutral posture and low force may create a different level of exposure from repetitive work involving forceful movements and sustained joint deviation.

Therefore, ergonomic assessment should consider the combination, frequency, and duration of relevant exposures.

Human-centred workplace design

A central principle of ergonomic compatibility is that workplace systems should accommodate the variation present within the working population.

Designing a workstation around a single assumed body dimension may create difficulties for employees whose physical characteristics differ from that reference.

Adjustability, suitable clearances, appropriate reach distances, and accessible controls can improve compatibility across a broader range of workers.

The design process should also consider employees with specific functional requirements. This is important not only for inclusion but also for the general reliability and usability of work systems.

Cognitive ergonomics and operational safety

Physical ergonomics is only one part of the broader human factors approach.

In modern industrial environments, employees may be required to monitor several indicators, respond to alarms, interpret complex information, and coordinate activities with other workers.

If information is presented poorly, warning signals are ambiguous, or the interface requires unnecessary mental effort, the probability of incorrect interpretation may increase.

Cognitive ergonomic improvements should therefore address information clarity, alarm prioritization, interface consistency, task complexity, and the organization of attention-demanding activities.

The objective is not simply to reduce the amount of information presented but to ensure that important information can be recognized and interpreted at the appropriate moment.

Organizational factors and ergonomic performance

Ergonomic compatibility is also influenced by organizational arrangements.

Even a well-designed workstation may become unsuitable when production schedules create excessive work intensity, employees have insufficient recovery opportunities, or tasks are distributed inefficiently.

For this reason, work organization should be considered part of ergonomic assessment.

The ILO and International Ergonomics Association guidelines emphasize the integration of physical, cognitive, and organizational human factors into work-system design [2].

This approach supports the argument that ergonomic improvements require cooperation between management, technical specialists, occupational safety professionals, and employees.

Economic and preventive significance

Ergonomic improvement may also have organizational and economic implications.

Excessive physical strain, fatigue, and discomfort can affect productivity, work quality, absenteeism, and the continuity of production processes.

However, economic benefits should not be treated as the only justification for ergonomic interventions. The primary objective remains the protection of workers' health, safety, and functional capacity.

The economic evaluation of ergonomic measures should consider both direct costs, such as equipment modification, and indirect consequences, including reduced work disruption and the prevention of work-related health problems.

Research limitations and future directions

The present study develops a conceptual model and a proposed assessment index. Its principal limitation is the absence of empirical validation through workplace measurements or controlled intervention studies.

Further research should focus on:

- Testing the six-dimensional model in different industrial sectors;
- Establishing reliable indicators for each compatibility dimension;
- Comparing ECI results with specialized ergonomic assessment methods;
- Examining the influence of workplace redesign on physical and cognitive workload;
- Determining appropriate weighting coefficients through expert evaluation;
- Assessing the long-term effectiveness of ergonomic interventions.

Such studies would help determine the reliability of the proposed model and clarify how it can be incorporated into occupational safety management systems.

Conclusion

Ergonomic compatibility is an essential element of occupational safety because it determines how effectively the working environment corresponds to the physical, physiological, and cognitive capabilities of employees.

The study demonstrates that incompatibility between human characteristics and workplace demands may develop through several interconnected factors, including unsuitable workstation dimensions, excessive physical loading, repetitive movements, inadequate recovery, complex information requirements, and unfavourable environmental conditions.

An original six-dimensional ergonomic compatibility model has been developed. It integrates anthropometric, biomechanical, physiological, cognitive, psychosocial-organizational, and environmental dimensions into a unified methodological framework.

The proposed Ergonomic Compatibility Index provides a conceptual basis for comparing workplace characteristics and identifying areas requiring improvement. It is intended to complement, rather than replace, specialized ergonomic assessment techniques and formal occupational risk management procedures.

A seven-stage mechanism for improving ergonomic compatibility has also been developed. It connects workplace characterization, human capability analysis, identification of mismatches, risk prioritization, corrective measures, employee participation, and continuous verification.

The principal scientific conclusion is that occupational safety should not be based exclusively on adapting employees to existing production conditions. Instead, work systems should be designed and continuously improved in accordance with the capabilities and limitations of the people who operate them.

In practical terms, ergonomic compatibility contributes to the prevention of excessive workload, the improvement of working conditions, the reduction of avoidable physical and cognitive strain, and the development of more reliable production processes.

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