A Comprehensive Review of Ergonomics Principles and Applications on Optimizing Workplace Performance and Well-being

FIDELIS MNE CHIA
Department of mechanical Engineering, Joseph Sarwuan Tarka University, Makurdi

Abstract- This paper delves into the interdisciplinary field of ergonomics, which aims to optimize workforce performance and well-being by aligning workplace elements with workers' capabilities. It explores the historical significance of ergonomics in mitigating musculoskeletal disorders (MSDs) and enhancing workplace productivity. Key concepts such as ergonomic modeling, musculoskeletal system biomechanics, and the ergonomic assessment of carrying, holding, and lifting tasks are discussed. Additionally, the paper examines the physiological aspects of work, including heart rate and energy expenditure measurements, and presents ergonomic assessment techniques such as the Nordic Musculoskeletal Questionnaire (NMQ), posture analysis, and rapid assessment tools like the Rapid Upper Limb Assessment (RULA) and the Rapid Entire Body Assessment (REBA). Furthermore, it outlines the fundamental concepts of Health, Safety, Environment, and Ergonomics (HSEE), emphasizing the importance of integrated approaches to enhance workplace safety and efficiency. This abstract provides a comprehensive overview of ergonomic principles, methodologies, and their applications in promoting occupational health and well-being.

Indexed Terms- Ergonomics, Musculoskeletal Disorders, Biomechanics, Work Physiology, Health and Safety, Environmental Factors, Human Factors, Workplace Optimization.

I. INTRODUCTION

Ergonomics, derived from the Greek words "ergon" (work) and "nomos" (natural laws), plays a crucial role in optimizing workforce performance and comfort within any organization. It involves aligning workplace elements with workers' capabilities to enhance efficiency, prevent accidents and health issues, and improve job satisfaction. Abu-Kasim et al. (2022) describe ergonomics as the study of human-machine interactions and interface design, aiming to match tasks to workers, thereby ensuring effective task completion. Historically, inadequate workstation design has led to the development of musculoskeletal disorders, particularly in industries like electronics, where prolonged standing contributes to lower limb pain (Deros et al., 2016b). Deros et al. (2016b) proposed an optimization model that considers environmental, technological, manpower, and methodological factors to enhance productivity and minimize risks.

William (2005) underscores the significance of work design in preventing health problems, advocating for the use of appropriate equipment, such as Personal Protective Equipment (PPE). Key aspects of ergonomics include the nature and demands of tasks, the suitability of equipment, the ergonomics of lifting and carrying, the presentation of information, and the physical environment, including factors like lighting, noise, humidity, and temperature.

Objectives of the Study:

1. To analyze the impact of ergonomic principles on reducing the incidence of musculoskeletal disorders (MSDs) in the workplace.
2. To evaluate the role of ergonomics in enhancing overall workplace productivity and employee well-being.
3. To explore the relationship between ergonomic interventions and the prevention of workplace injuries.
4. To identify and address the gaps in current ergonomic research, including the development of comprehensive ergonomic models, standardized

assessment methods, and the need for longitudinal studies.

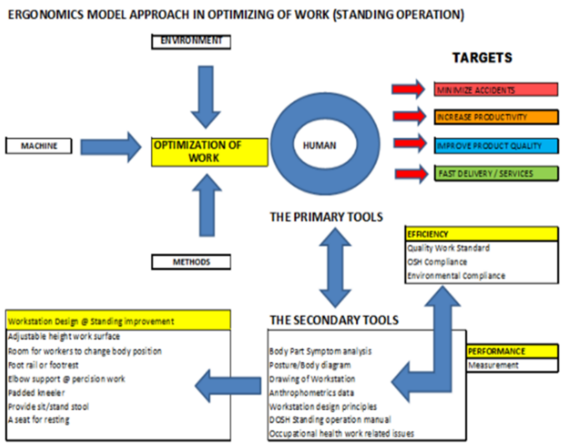

Figure 1: Ergonomic model approach for work optimization

Source: Deros *et al*., (2016b)

The model proposed by Deros et al. (2016b) offers a robust framework for optimizing work environments, particularly in contexts that involve standing operations. This model adopts a holistic approach to ergonomics, aiming to enhance workplace safety, productivity, and employee comfort by addressing key ergonomic factors. Critically, the model's primary tools are designed to ensure strict adherence to ergonomic standards and regulatory compliance, which is essential for mitigating risks associated with poor workplace design. These tools play a crucial role in identifying areas where current practices may fall short of industry standards, thereby facilitating necessary adjustments to improve overall worker health and safety.

The secondary tools within the model provide a more granular analysis, offering specific guidelines and recommendations tailored to particular ergonomic challenges. This level of detail is vital for addressing the nuanced needs of different work environments, particularly in industries where the risk of musculoskeletal disorders is high due to prolonged standing or repetitive tasks.

However, while the model's focus on workstation design is commendable, its effectiveness hinges on the practical implementation of its recommendations. Without proper enforcement and ongoing assessment, even the most well-designed ergonomic models can fall short in real-world applications. Moreover, the model's emphasis on compliance may overlook the dynamic nature of workplace environments, where continuous adaptation and worker feedback are crucial for sustaining ergonomic improvements.

- Muscular Skeletal System (Biomechanics)

Muscles are categorized into action muscles, known as protagonists, and opposer muscles, referred to as antagonists. Body movement is the result of the coordinated interaction between bones, ligaments, and tendons, which are structured into three types of levers: first class (e.g., the jawbone), second class (e.g., the leg and foot with the fulcrum on the toes), and third class (e.g., the arm with the fulcrum at the elbow). The mechanical advantage provided by these levers can vary significantly due to individual differences in factors such as limb length, body weight, muscle attachment points, and the angles formed between limbs.

The importance of maintaining proper work angles cannot be overstated, as incorrect angles can lead to a host of health issues, including musculoskeletal disorders (MSDs). By focusing on ergonomically sound workstation design and tools, industries can significantly reduce the risk of such disorders. This is achievable through the application of a robust biomechanical approach, which takes into account the varying physical characteristics and capabilities of workers. Vijaywargiya (2020) emphasizes that by implementing these ergonomic principles, industries can effectively eliminate many of the primary causes of MSDs, thereby promoting a healthier and more productive workforce.

- Musculoskeletal Disorders (MSDs)

Abu-Kasim et al. (2022) identify work-related musculoskeletal disorders (WMSDs) as a significant ergonomic challenge across various industries. These disorders negatively impact productivity, increase medical costs, and decrease worker morale. Key risk factors contributing to WMSDs include excessive force, poor posture, repetitive motions, fatigue, workspace layout, load handling, cycle time, working shifts, and inadequate rest patterns. Common ergonomic assessment methods, such as surveys and posture analysis, are employed to detect discomfort, pain, and fatigue, which are often precursors to more severe injuries.

Jagadish et al. (2018) describe WMSDs as impairments affecting joints, tendons, muscles, nerves, ligaments, bones, and circulation, all of which can be caused by unfavorable work conditions. These disorders frequently result from awkward postures, such as bending, twisting, and carrying heavy loads. The garment industry, in particular, is at high risk for WMSDs, with common injuries including sprains, strains, cumulative trauma disorders (CTDs), carpal tunnel syndrome (CTS), and tendonitis (Subtrata and Subhalakshmi, 2022).

- Effect of Musculoskeletal Disorders

Musculoskeletal disorders (MSDs) represent a significant and ongoing challenge, with profound implications for both worker health and the global economy. These disorders are not only a major cause of disability among workers but also contribute to substantial economic losses due to reduced productivity, increased healthcare costs, and compensation claims. Seidel et al. (2019) underscore the pervasive nature of MSDs, which continue to affect a wide range of industries, highlighting the urgent need for effective preventive measures and interventions.

The International Labour Organization (ILO) estimates that approximately 2.78 million workers lose their lives annually as a result of occupational accidents and diseases, a statistic that underscores the severity of workplace safety issues worldwide (Sukri and Lilin, 2021). This staggering figure includes fatalities linked to MSDs, which are often preventable with proper ergonomic practices and safety protocols. The high incidence of work-related MSDs reflects systemic failures in workplace design, safety culture, and employee training.

A closer examination of industry-specific data reveals that certain sectors are particularly vulnerable to MSDs. Surenda (2024) reports that between 2017–2018 and 2020–2021, the construction industry accounted for 19% of all musculoskeletal disorder claims, with the manufacturing industry contributing an additional 5.4%. These statistics suggest that industries characterized by physically demanding tasks, such as heavy lifting, repetitive motions, and awkward postures, are at heightened risk for MSDs. However, the relatively lower percentage in manufacturing may indicate underreporting or inadequate recognition of MSDs in this sector, where repetitive strain injuries and ergonomic risks are also prevalent.

Critically, the impact of MSDs extends beyond the immediate physical health of workers. These disorders can severely impair an individual's ability to perform daily tasks, diminishing their overall quality of life. Workers suffering from MSDs may experience chronic pain, limited mobility, and long-term disability, which not only affect their professional lives but also strain their personal lives and social relationships. This, in turn, can lead to psychological issues such as anxiety and depression, further exacerbating the negative effects on their well-being.

Moreover, the economic burden of MSDs is substantial. Businesses face direct costs related to medical treatment and compensation, as well as indirect costs from lost productivity, absenteeism, and employee turnover. The construction industry, in particular, is notorious for high turnover rates, partly due to the physical demands and associated risks of the job. Employers must also contend with the challenges of recruiting and training new workers, which adds to operational costs.

- Work-related Risk Factors for Musculoskeletal Disorders

According to Berberoglu and Tojuc (2013), work-related musculoskeletal disorders (WMSDs) have been a concern since Bernardino Ramazzini first identified these conditions. Ramazzini observed that workers performing "insistent and irregular movements in unnatural postures" were prone to developing musculoskeletal issues. His early documentation highlighted the connection between specific work activities and disorders affecting the neck, shoulders, lower back, upper limbs, and other musculoskeletal regions. These disorders remain a significant concern for workers, researchers, and companies due to their severe implications, including temporary or permanent disability, symptoms such as pain, numbness, and tingling, absenteeism, reduced productivity, increased compensation costs, and a rising number of legal cases related to these conditions (Berberoglu & Tojuc, 2013).

Berberoglu and Tojuc (2013) emphasize that WMSDs have become a major issue in many industrialized countries, where these disorders are not only widespread but also incur substantial economic and social costs. WMSDs constitute a significant proportion of all registered and compensation-eligible work-related diseases, reflecting their broad impact on the workforce. The prevalence of these disorders is particularly high in manual-intensive occupations such as clerical work, postal services, cleaning, industrial inspections, and packaging, where workers are often exposed to risk factors that contribute to upper-extremity musculoskeletal disorders (Berberoglu & Tojuc, 2013).Both experimental research and epidemiological studies confirm that certain job features significantly increase the risk of WMSDs. Key risk factors include heavy lifting, repetitive hand motions, prolonged static postures, exposure to vibrations, and the interaction of these physical demands with a negative psychosocial work environment. Such combinations of physical and psychosocial stressors create a high-risk environment that can lead to the onset of WMSDs, complicating efforts to mitigate their impact (Berberoglu & Tojuc, 2013).

The persistent prevalence of WMSDs across various industries highlights the need for more effective preventive measures. Despite decades of research and numerous interventions, WMSDs remain a major health concern, suggesting that current approaches may be insufficient or inadequately implemented. This situation indicates a gap between scientific knowledge and practical application, where ergonomic principles and worker safety practices are not consistently or comprehensively applied (Berberoglu & Tojuc, 2013). Furthermore, addressing WMSDs requires a holistic approach that not only modifies physical work conditions but also enhances the overall work environment. This includes factors such as job satisfaction, worker autonomy, and support systems. Without addressing the full spectrum of contributing factors, efforts to reduce the incidence of WMSDs may fall short, leading to continued high rates of these disorders and their associated costs (Berberoglu & Tojuc, 2013).

- Ergonomics of Carrying, Holding, and Lifting

Carrying: Continuous carrying is primarily constrained by the cardiovascular system's capacity. To optimize safety and reduce strain, it is crucial to adhere to key principles: minimize the load's movement arm relative to the spine, prefer carrying large loads occasionally rather than lighter loads frequently, and avoid placing items on the ground to reduce vertical body movement. These strategies help in reducing the physical strain on the cardiovascular system and enhancing overall efficiency in carrying tasks.

Holding: When holding loads, it is essential to consider the weight on each arm independently. For instance, holding 25 kg in each hand is equivalent to managing 25 kg on each hand separately. The relationship between the weight of the object and the duration it is held follows an exponential curve, indicating that as the holding time increases, the perceived weight and strain increase disproportionately.

Lifting: The safety of lifting tasks is influenced by several factors, including the nature of the load, the technique used for lifting, the environment, and the individual performing the lift. To mitigate the risk of back injuries, it is advisable to avoid heavy lifting whenever possible, utilize technical aids, keep the load close to the body, and refrain from lifting and twisting simultaneously. Lifting tasks can be categorized into repetitive and occasional types, each requiring specific considerations to ensure safe handling practices.

- Ergonomics and Health Measurements

Heart Rate and Blood Pressure: Heart rate and blood pressure are critical physiological measurements controlled by the autonomic nervous system, which includes the parasympathetic and sympathetic systems. These systems maintain body equilibrium.

Heart rate, determined by metabolic load, is highly correlated with incremental metabolic rates, though the linear equation varies for different individuals and work types:

$$INCHR=K+0.12INCEMETINCHR=K+0.12INCEMET$$

where INCHR is the increase in heart rate (beats/min), K is a constant (2.3 for arm work; 11.5 for walking or walking + arm work), and INCEMET is the increase in metabolism (W). Arm work without legwork requires 14 more beats/min than legwork at the same metabolic rate due to venous pooling in the legs.

Maximum heart rate (HRMAX) can be predicted using age-based formulas (Astrand and Rhyming, 1954):

$HRMAX=220-A HRMAX=220-A$

As revealed by Robert and Roberto (2002), no formula provides accuracy of HRMAX prediction.

There are three common ways of measuring an individual heart rate; by palpation, by sound, and by electronics. Many research has been carried out on the use of wireless detecting technology in heart rate measurement (Mahmood *et al*., 2011; Zulkifli *et al*., 2012; Liu and Yu, 2013; Larki and Ruileng, 2015).

Heart rate is a good index of task difficulty and can be estimated by perceived exertion (Borg, 1982). The perceived exertion scale correlates with 10% of the heart rate. Table 1 below outlines measurements and correlations related to heart rate and exertion.

Table 1: Cardiovascular Considerations in Physical Work

Category	Description	Details	References
Maximum Heart Rate Formula	Formula to predict maximum heart rate.	$HRMAX=220-A HRMAX=220-A$	Astrand and Rhyming (1954)
Heart Rate Measurement Methods	Methods to measure heart rate.	- wireless detection technology	Zulkifi et al., (2012); Liu and Yu, (2013); Larki and Ruileng (2015)
Perceived Exertion	Heart rate as an index of task difficulty can be estimated by perceived exertion.	The perceived exertion scale corresponds to 10% of the heart rate.	Borg (1982)

Table 2: Borg's Scale and Cardiovascular Parameters

Task	Perceived Exertion (Borg Scale)	Source
Very, very light	6	Borg (1962)
Very light	9	
Fairly light	11	
Hard	15	
Very hard	17	
Very, very hard	19	

Table 2 presents Borg's Scale alongside corresponding perceived exertion ratings for different tasks, spanning from very, very light to very, very hard. The scale, introduced by Borg in 1982, offers a subjective measure of exertion levels during physical activities. Tasks are categorized based on perceived effort, with ratings increasing as tasks become more strenuous. For instance, activities classified as very, very light correspond to a rating of 6 on the Borg Scale, while those deemed very, very hard are assigned a rating of 19. This table serves as a reference tool for assessing perceived exertion during various tasks, aiding in the evaluation of workload and exertional demands in different settings.

Insights into Work Physiology and Energy Expenditure

Work physiology applies physiological techniques to manual work, aiming to gauge physical stress levels by observing changes such as heart rate and oxygen consumption. Passmore and Durnin (1955) provide energy expenditure measurements for various activities, ranging from 5.0 cal/min to 9.8 cal/min. Datta and Ramanathan (2007) demonstrate how different load-carrying methods affect energy expenditure, with maintaining good postural balance being the most efficient. McCormick and Sanders (1982) highlight that task efficiency depends on both activity pace and age. Pontzer *et al.*, (2015) estimated that the total energy expenditure for a 65 kg eutherian mammal is 5,550 kcal/day. These insights aid in assessing acceptable energy expenditure limits during work activities.

This table 3 below outlines the grading of work according to energy expenditure and oxygen consumption. The grading system provides a framework for assessing the physical demands of various tasks based on their energy expenditure rates and corresponding oxygen consumption levels. Work is categorized into six grades, ranging from "Unduly heavy" to "Very light," with specific ranges for approximate oxygen consumption (in litres per minute), energy expenditure (in kilocalories per minute), and total energy expenditure over an eight-hour period (in kilocalories). This grading system offers valuable guidance for evaluating the intensity of different workloads and aids in designing strategies for managing and optimizing human performance in occupational settings. The data presented in this table are sourced from Passmore and Durnin (1955), providing foundational insights into the physiological aspects of work assessment.

Table 3: Grading of Work based on Energy Expenditure and Oxygen Consumption

Grade of Work	Approx. Oxygen Consumption (litre/min)	Energy Expenditure (kcal/min)	Energy Expenditure (kcal/8hr)
Unduly heavy	Over 2.5	Over 12.5	Over 6,000
Very heavy	2.0-2.5	10.0-12.5	4,800-6,000
Heavy	1.5-2.0	7.5-10	3,600-4,800
Moderate	1.0-1.5	5.0-7.5	2,400-3,600
Light	0.5-1.0	2.5-5.0	1,200-2,400
Very light	Under 0.5	Under 2.5	Under 1,200

- Measurement Techniques
- Nordic Musculoskeletal Questionnaire (NMQ)

The Nordic Musculoskeletal Questionnaire (NMQ), adapted by Health, Safety, and Environment (HSE) agencies, is widely utilized across different workforces, including supermarket workers and lock assemblers, to assess musculoskeletal issues such as pain and discomfort. The NMQ is structured into three sections: personal details, job-related information, and inquiries about musculoskeletal disorders affecting nine body regions. Additionally, respondents evaluate their perceived exertion using Borg's scale.

Any modifications to the NMQ could introduce complexities, necessitating thorough validation and piloting to ensure reliability and effectiveness (Dickinson et al., 1992; Ikpambese et al., 2017). The careful management of these modifications is essential to maintain the questionnaire’s accuracy and applicability in diverse occupational settings.

- Heart Rate Measurement

Heart rate monitoring using Polar Heart Rate Monitors is a valuable method for evaluating energy requirements during work shifts. This technology aids in assessing the physical demands of different tasks by comparing them against established levels of strenuousness (Saha, 1979). By providing real-time data on cardiovascular responses, Polar Heart Rate Monitors help in understanding the intensity of work activities and ensuring that tasks remain within safe and manageable limits. This approach supports efforts to optimize work conditions and improve overall workplace ergonomics.

- Ergonomic Assessments
- Posture Analysis

Video recordings are used to assess worker postures with the aid of tools like OWAS (Occupational Work Analysis Software), which classifies postures into action categories based on their perceived harmfulness (Figlali et al., 2015; Ozkaya et al., 2018). This method provides a detailed analysis of how different postures contribute to musculoskeletal risks.

In addition to these tools, European standards such as EN-614-1 and EN-1005-4 offer guidelines and parameters designed to mitigate musculoskeletal risks associated with workplace ergonomics (Berberoglu & Tojuc, 2013). These standards help in establishing safe working conditions and promoting practices that reduce the likelihood of musculoskeletal disorders.

- Rapid Upper Limb Assessment (RULA)

The Rapid Upper Limb Assessment (RULA) is a widely used tool designed to assess biomechanical loading on the neck, trunk, and upper limbs. It provides a systematic method for evaluating postural risk factors and determining the need for ergonomic interventions based on observed postures and external loads. RULA is particularly effective for tasks that involve prolonged sitting or repetitive upper limb movements and is valued for its simplicity and ease of use, as it requires no special equipment. This makes it a practical choice for assessing and addressing ergonomic issues in various work settings (Qutunbuddin et al., 2013b).

- Rapid Entire Body Assessment (REBA)

The Rapid Entire Body Assessment (REBA) is an effective tool for conducting a comprehensive postural analysis of entire activities. It assigns risk levels based on the assessment and provides recommendations for necessary interventions. REBA evaluates a range of postures, including static, dynamic, and unstable positions, making it adaptable to various industries and work environments. This tool is particularly useful for identifying potential ergonomic issues and guiding improvements to enhance worker safety and reduce musculoskeletal risk (Qutunbuddin et al., 2013b; Deros et al., 2016a).

- Basic Concept of Health, Safety, Environment, and Ergonomics (HSEE)

The relationship between health, safety, environment, and ergonomics (HSEE) is intricate and significant. Ergonomics focuses on factors that impact individuals and their behavior, emphasizing the importance of appropriate design to ensure safety and efficiency. Poor design, particularly between humans and machines, can lead to decreased safety and management errors, which in turn can result in human error (Azadeh et al., 2015).

Ergonomics encompasses various elements affecting individuals and their behavior at work. Inappropriate system design can lead to safety issues and management errors, which are harmful factors contributing to human error (Azadeh et al., 2008). According to Health, Safety, and Environment (HSE) definitions, human factors and ergonomics involve understanding how environmental, organizational, and individual factors influence workplace behavior. The goal is to enhance health and safety outcomes while reducing costs associated with workplace accidents (Azadeh et al., 2008).

Integrated frameworks for HSEE models, such as the total ergonomics approach, have been proposed to improve safety and efficiency in various work settings (Azadeh et al., 2008). Research has also focused on methods for assessing health risks and evaluating the performance of occupational health and safety management systems, providing insights into improving safety and operational effectiveness (Hassim & Hurme, 2010; Chang & Liang, 2009).

- Research Gap:

Despite extensive research on ergonomics, musculoskeletal health, and safety across various industries, there remains a significant gap in understanding the comprehensive integration of ergonomic principles and their practical application in effectively addressing musculoskeletal disorders (MSDs). Existing literature provides valuable insights into ergonomic assessments, techniques, and interventions; however, there is a pressing need for further research to bridge the divide between theoretical knowledge and practical implementation strategies.

Current research often lacks exploration into the development and evaluation of holistic ergonomic models that account for multiple factors influencing workplace health and safety outcomes. Additionally, there is a notable absence of standardized methods for assessing the effectiveness of ergonomic interventions and management systems, particularly within diverse occupational settings. This gap hinders the ability to apply ergonomic principles consistently and effectively.Moreover, there is a deficiency of research investigating the long-term impacts of ergonomic interventions on reducing MSD incidence and improving overall worker well-being. Addressing these research gaps is crucial for enhancing the efficacy of ergonomic practices and fostering a safer, healthier work environment across various industries. By focusing on these areas, future studies can contribute to the development of more comprehensive and practical solutions for mitigating musculoskeletal disorders and improving workplace health.

CONCLUSION

In conclusion, this literature review highlights the significance of ergonomics, musculoskeletal health, and safety in optimizing workplace performance and ensuring employee well-being. The integration of ergonomic principles into work design and management systems is essential for preventing musculoskeletal disorders (MSDs), reducing workplace injuries, and enhancing overall productivity. The review underscores the complex interplay of physical and psychosocial factors contributing to MSDs and emphasizes the importance of addressing both aspects in ergonomic interventions. Furthermore, the review identifies key gaps in current research, including the need for comprehensive ergonomic models, standardized assessment methods, and longitudinal studies to evaluate the long-term effectiveness of interventions. Bridging these gaps requires interdisciplinary collaboration, innovative research methodologies, and a focus on translating theoretical knowledge into practical solutions.

RECOMMENDATIONS

Based on the findings of this review, the following recommendations are proposed:

1. Development of Comprehensive Ergonomic Models: Researchers should focus on designing holistic ergonomic models that integrate environmental, organizational, and individual factors to address the complex nature of workplace health and safety.
2. Standardization of Assessment Methods: Efforts should be made to standardize ergonomic assessment methods and metrics to facilitate comparison across studies and industries, enabling more effective evaluation of interventions.
3. Longitudinal Studies: Long-term studies are needed to assess the sustained impact of ergonomic interventions on reducing MSDs and improving worker well-being over time.
4. Interdisciplinary Collaboration: Collaboration between researchers, practitioners, and policymakers from diverse fields is essential to develop evidence-based ergonomic interventions and promote their implementation in various occupational settings.
5. Knowledge Translation: Efforts should be made to bridge the gap between research and practice by translating findings into practical guidelines, training programs, and policy recommendations for organizations and stakeholders.

By implementing these recommendations, stakeholders can work towards creating safer, healthier, and more productive work environments that prioritize the well-being of employees while enhancing organizational performance.

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