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Research on the Assessment Methods of Work-Related Musculoskeletal Disorders in Human-Machine Collaboration in the Industry 5.0 Era: Focusing on Subjective Judgment and Systematic Observation Methods

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***Abstract*—Industry 5.0, as an emerging stage of industrialization, is reshaping the global industrial landscape. This phase emphasizes a human-centered approach, placing the well-being of workers at the core of the production process. In the context of human-machine collaboration, work-related musculoskeletal disorders (WMSDs) are a critical issue. In recent years, various assessment methods have been developed to quantify and analyze the relationship between factors such as the work environment, posture, tool usage, and WMSDs. The methods for assessing WMSDs are mainly divided into three categories: subjective judgment, systematic observation, and direct measurement. Considering that direct measurement typically requires expensive equipment and complex operations, making it difficult to apply widely in resource-constrained work environments, this paper focused on subjective judgment and systematic observation methods. This paper analyzed the commonly used subjective judgment and systematic observation methods for assessing WMSDs, summarized both domestic and international research findings and practical cases. It comprehensively evaluated the effectiveness of these methods, analyzing their roles in identifying at-risk populations, predicting WMSDs, and guiding intervention measures. Through a systematic analysis of WMSDs assessment methods, this paper provided practical references for workplace prevention and management, with the aim of effectively integrating the work state of digital humans into digital twin technology in the era of Industry 5.0.**

Keywords-Industry 5.0; work-related musculoskeletal disorders (WMSDs); Subjective judgment method; systematic observation method

I. INTRODUCTION

Industry 5.0, an emerging stage of industrialization, is reshaping the global industrial landscape with its core principles, key characteristics, and applications. The core ideas of Industry 5.0 include human-centeredness, sustainability, and resilience, shifting focus from mere efficiency and productivity to prioritizing worker well-being. By leveraging new technologies, Industry 5.0 seeks to foster prosperity beyond just employment and growth, while respecting production limitations and environmental protection. The human-centered design principle calls for integrating this concept not only in human-machine collaboration but from the very beginning of manufacturing planning, ensuring the seamless incorporation of digital humans into digital twin technology during both the manufacturing process and system design stages.

In human-centered design, Work-Related Musculoskeletal Disorders (WMSDs) are a critical issue in human-machine collaboration. WMSDs refer to injuries or pain in the muscles, bones, joints, ligaments, tendons, or nervous system, caused by factors such as work activities, environment, or organizational methods[1]. These disorders are often chronic, recurrent, and multifactorial, arising from intense physical activity or cumulative damage from prolonged poor posture, repetitive movements, or vibration exposure[2], as shown in Figure 1. Beyond physical health, WMSDs can also cause psychological distress, such as anxiety and depression, which further reduce quality of life and work efficiency[3].

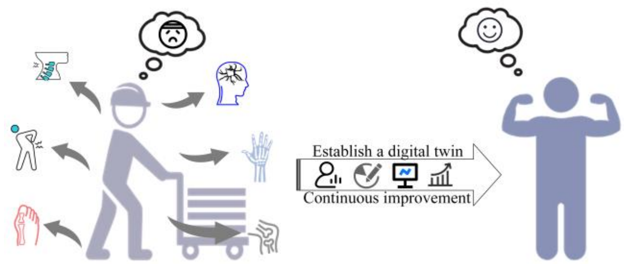

Figure 1. Reducing WMSDs by Establishing Digital Human

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Therefore, enhancing WMSDs assessment, prevention, and management is vital not only for safeguarding workers' health but also for promoting sustainable societal and economic development.

II. Evaluation Methods

WMSDs assessment methods are categorized into three types: subjective judgment, systematic observation, and direct measurement[4]. The subjective judgment method relies on interviews or surveys, where respondents self-report their conditions. This method is quick and convenient, but the results are subjective and may be limited by the respondents' ability to express themselves and their understanding of the questions. The systematic observation method involves on-site observation and recording of ergonomic hazards, making it suitable for repetitive tasks and more standardized and scientific in nature. The direct measurement method uses sensors and instruments (e.g., electromyography, motion capture, etc.) to directly measure posture, movements, and loads. This method offers high precision but is limited by the high cost of equipment, complex operation, and the potential for interference with natural work behaviors, making it less applicable in real-world work environments. Consequently, the subjective judgment and observation methods are the most widely used assessment methods[5]. This study primarily reviews the subjective judgment and systematic observation methods currently used to assess WMSDs, analyzing their characteristics, exploring their applicability in different industries and job positions, and providing directional suggestions for future research and practice.

A. *Subjective Judgment Methods*

1) *Method Overview*

a) *Nordic Musculoskeletal Questionnaire (NMQ)*

NMQ is a standardized survey tool primarily used to assess discomfort or injury to the musculoskeletal system of individuals in the workplace[6]. The questionnaire was developed by Kuorinka in 1987 and divides the human body into nine main anatomical regions, including the neck, shoulders, upper back, lower back/waist, elbows, hands/wrists, hips/thighs, knees/ankles/feet. Participants are asked to mark areas where they have experienced discomfort or injury over a specific period (e.g., the past 12 months). The questionnaire may include questions about the severity and duration of symptoms, as well as the impact on work or daily life. Research has consistently confirmed that the NMQ demonstrates good reliability and validity.

b) *Dutch Musculoskeletal Questionnaire (DMQ)*

DMQ is a standardized tool for assessing musculoskeletal health[7]. The questionnaire contains 63 questions covering basic information (such as age, gender, occupation), work tasks (frequency of heavy lifting or physically demanding tasks), musculoskeletal symptoms (pain, discomfort, or dysfunction), work-related factors (such as prolonged standing, heavy lifting, and environmental conditions), and lifestyle habits (diet, exercise, sleep, etc.). By analyzing the responses, the DMQ assesses musculoskeletal health status, identifies high-risk groups, and provides a basis for the prevention of WMSDs.

c) *Maastricht Upper Extremity Questionnaire (MUEQ)*

MUEQ is primarily used to assess upper limb musculoskeletal injuries in occupational environments caused by psychosocial factors. The questionnaire quantifies the impact of work control (such as autonomy in deciding task pace and methods), job demands (such as task load and time pressure), and social support (from colleagues and management) on upper limb health. It is particularly suitable for occupational groups that involve prolonged use of the upper limbs, such as office workers using computers and manufacturing workers, who face higher injury risks due to prolonged fixed postures or repetitive movements[8].

d) *McGill Pain Questionnaire(MPQ)*

MPQ is a method used to assess the nature and intensity of pain, often employed to gather information related to WMSDs[9]. In manufacturing, workers commonly experience pain caused by WMSDs due to repetitive tasks, high-intensity labor, and poor posture, especially in processes such as assembly, material handling, and welding. The MPQ evaluates pain intensity through a variety of descriptive terms (such as sensory, affective, and evaluative categories). Participants select words that best describe their current pain from a list, marking their chosen words along a line, with the position of the mark indicating pain intensity. By aggregating and analyzing these results, the nature, intensity, and impact of the pain on daily life can be understood.

e) *Örebro Musculoskeletal Pain Screening Questionnaire (OMPSQ)*

OMPSQ is used to predict high-risk populations for chronic musculoskeletal pain through psychosocial factors[10]. The questionnaire includes multiple questions regarding pain location, intensity, duration, its impact on daily life, and the patient’s psychological state. The questions typically focus on the following core aspects: pain location (such as neck, back, or waist), pain intensity (using tools such as the Visual Analog Scale, VAS), pain duration (e.g., episodic or persistent), the impact of pain on daily life (such as sleep, activity levels, and work efficiency), and psychological factors (such as the influence of anxiety or depression on pain perception).

f) *STarT Back Screening Tool (SBST)*

SBST questionnaire contains 9 items and assesses the chronic risk of back disorders, categorized into low, medium, and high-risk levels. Low risk: no or few risk factors; medium risk: high physical scores but low psychosocial risk; high risk: poor recovery with high psychosocial scores. The assessment includes factors such as the spread of back pain, walking ability, dressing, exercise capability, and health concerns. It is widely used to predict the risk of acute and subacute low back pain progressing to chronic conditions[11]. Employees in manufacturing are at high risk due to repetitive tasks and poor posture. The SBST helps in the early identification and classification of risk, providing a basis for intervention and evaluating the effectiveness of health management measures within enterprises.

g) *Acute Low Back Pain Screening Questionnaire (ALBPSQ)*

ALBPSQ predicts chronic low back pain by assessing biological, psychological, and social factors. It covers pain intensity, duration, life impact, anxiety, depression, and work/lifestyle conditions, aiding personalized treatment. In labor-intensive industries, prolonged standing, repetitive tasks, and poor posture worsen pain. Recent studies validate its effectiveness in predicting chronicity and its link to other clinical indicators[12].

2) *Method Summary*

There are numerous methods of subjective judgment, each with its unique advantages and applicable contexts. Therefore, when selecting the most appropriate method for studying the extent of musculoskeletal injuries, a variety of factors must be considered. TABLE I. not only summarizes the basic characteristics of these seven subjective judgment methods but also provides several dimensions to help researchers make an appropriate choice.

TABLE I. BASIC CHARACTERISTICS AND APPLICATION GROUPS OF SEVEN SUBJECTIVE JUDGMENT METHODS

Method	characteristics	application groups
NMQ	Only the symptoms and effects of musculoskeletal disorders were investigated	Office staff[13]
DMQ	Comprehensive overview of possible risk factors and incidence rate	Handicraft workers[14]
MUEQ	The questionnaire for the upper limbs focuses more on measuring social and psychological factors	Office staff[15]
MPQ	Can reflect the comprehensive impact of pain on the psychological and emotional aspects of patients	People with pain symptoms in various fields[16]
OMPSQ	Has high predictive power for musculoskeletal disorders	Patients with chronic lower back pain[17]
SBST	Questionnaire for the waist and back	Patients with lower back pain [18]
ALBPSQ	Questionnaire for the waist	Patients with lower back pain[19]

Although subjective judgment methods can directly reflect employees' subjective experiences, their limitations include susceptibility to psychological states, emotional fluctuations, and other subjective factors, which may lead to biased assessment results. Additionally, reliance on employees' memory can introduce recall bias, and these methods often lack detailed analysis of specific work behaviors and precise quantitative data.

B. *Systematic Observation Methods*

1) *Method Overview*

a) Posture, Load, and Individual-based Ergonomic Assessment（PLIBEL)

PLIBEL identifies and analyzes ergonomic risk factors in the workplace that may cause WMSDs[20]. These disorders are linked to poor posture, repetitive movements, and excessive force, impacting both health and work efficiency. PLIBEL is suitable for tasks with frequent movements, intense physical labor, or prolonged specific postures. It assesses posture, force usage, working hours, tools, layout, and psychosocial factors, offering scientific support for improvement measures to reduce WMSDs incidence.

b) NIOSH Lifting Equation

The NIOSH Lifting Equation is an index-based tool to assess hazards in material handling tasks, see Figure 1. It calculates the Lifting Index (LI) and Recommended Weight Limit (RWL) by analyzing lifting movements, providing data to determine safe lifting loads. Its goal is to reduce the risk of back musculoskeletal injuries by optimizing lifting weight and techniques, as shown in Figure 2.

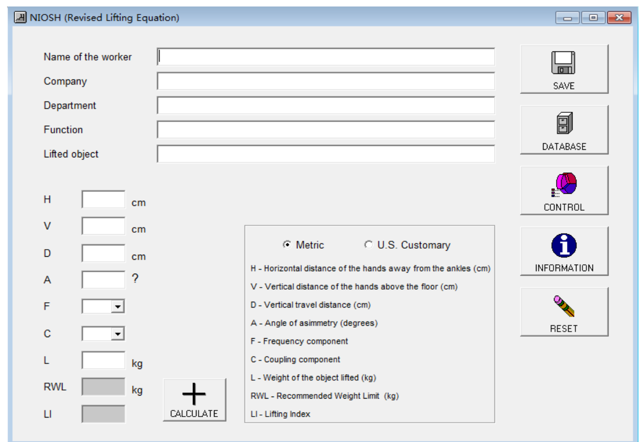

Figure 2. Calculation page of NIOSH Lifting Equation

c) Baseline Risk Identification of Ergonomic Factors (BRIEF)

BRIEF identifies ergonomic hazards in workplaces leading to WMSDs[21]. It analyzes work environment, tasks, and employee behaviors for comprehensive, specific risk identification and personalized improvements, boosting efficiency while lowering health risks. It focuses on work layout and equipment compatibility with ergonomics, assessing posture, force use, working time/frequency, and environment to reduce ergonomic injuries.

d) Rapid Upper Limb Assessment (RULA)

RULA, by University of Nottingham, scores employee posture comprehensively, assessing upper limb posture, muscle use, load, task duration, and frequency to prevent WMSDs. Suitable for manufacturing, assembly lines, and office work[22], it uses components shown in Figure 3. for posture assessment.

e) Ovako Working Posture Analysis System(OWAS)

OWAS, proposed by OvakoOy Steel in 1973, assesses improper work postures involving the back, arms, legs, and load. The back has four postures (upright, bent, twisted, or combined); the arms have three (both below shoulder level, one at or above, both at or above); the legs have seven (sitting, straight, squatting, kneeling, and walking); and the load is categorized into three weights (≤10kg, >10kg ≤20kg, >20kg) as shown in Figure 4. The danger level of each posture is evaluated based on site conditions.

Figure 3. Evaluation Content of RULA

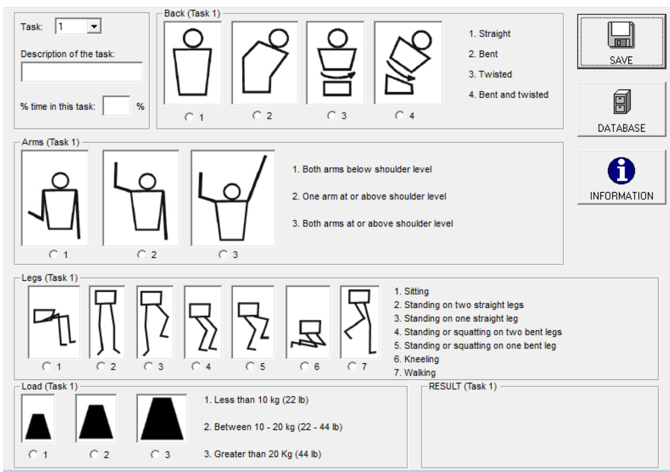

Figure 4. Evaluation Content of OWAS

f) Rapid Entire Body Assessment (REBA)

REBA, developed from RULA, OWAS, and NIOSH, evaluates risks from posture and movements. It divides the body into six parts: wrist, upper arm, lower arm, legs, neck, and torso. Scores are assigned based on posture and load, followed by a comprehensive evaluation of movement type and repetition, as shown in Figure 5. It assesses whole-body tasks, stable/unstable postures, load handling, and hazardous behaviors.

g) Quick Exposure Check (QEC)

QEC is used to assess the ergonomic load levels on various body parts (such as the neck, shoulders, wrists, etc.) to provide a basis for intervention measures. The QEC combines self-assessment and observer assessment to quickly identify the exposure levels of the back, shoulders, wrists, and neck. It is widely applied in industries involving repetitive tasks, poor posture, or high-intensity physical activity, such as power supply, shipbuilding, automotive manufacturing, and footwear production[23].

h) Muscle Fatigue Assessment (MFA)

MFA measures worker discomfort and fatigue by prioritizing musculoskeletal factors (force, duration, and frequency). It covers areas like the neck, shoulders, back, arms, wrists, legs, and feet. The force level, duration, and frequency are assessed, followed by cause analysis using a priority scale. Improvement strategies are proposed and re-evaluated for effectiveness.

i) Occupational Repetitive Action Methods (OCRA)

OCRA is used to assess the risk of WMSDs caused by repetitive tasks. The assessment covers four risk factors: repetitiveness, force, poor posture and movements, and lack of adequate rest time. Each factor provides options and assigns scores, with the overall score used to classify the risk into five levels: acceptable risk, very low risk, low risk, medium risk, and high risk.

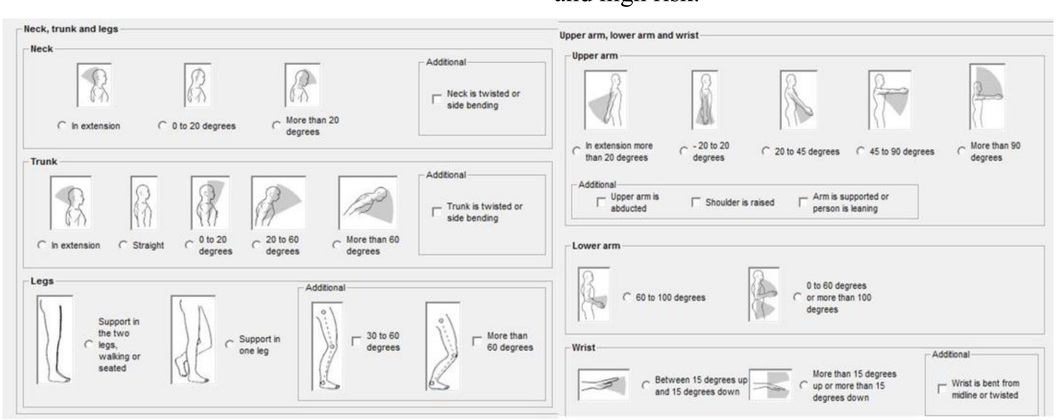

Figure 5. Evaluation Content of REBA

j) Ergonomic Assessment WorkSheet (EAWS)

EAWS is a biomechanical load assessment method used to evaluate operators' exposure to WMSDs risks[24]. It consists of four components: posture and movement, force, manual material handling, and upper limb load. The first three levels assess overall physical load, while the fourth level focuses on upper limb load. EAWS provides pre calculated values, and users select values based on actual observation results. The goal of EAWS is to quickly map risk areas in work tasks, with a focus on improving task design. Compared with other methods, EAWS has comprehensiveness and high operability, which can systematically evaluate various ergonomic factors and provide specific improvement suggestions. TABLE II. shows the standards of the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO) related to risk areas, interconnectivity, and risk related tools. It effectively prevents WMS and improves employee health and work efficiency. Figure 6. Figure 5. shows the EMA software developed by MTM SOLUTIONS GmbH, which establishes digital humans on EMA to achieve EAWS computing and realize digital twins in the Industry 5.0 era.

TABLE II. STANDARDS AND TOOLS RELATED TO EAWS

Risk area	Standardization		Related Tools
	CEN(European Committee for Standardization)	ISO(International Organization for Standardization)	
Body posture with minimal external force	1005-4	11226	OWAS
Force	1005-3	11228-2	RULA
Manual material handling	1005-2	11228-1	NIOSH
Upper limbs - high frequency/low load	1005-5	11228-3	OCAR、Strain Index、HAL-TV

Sourced from Overview of advances in evaluation methods for ergonomic exposure[24].

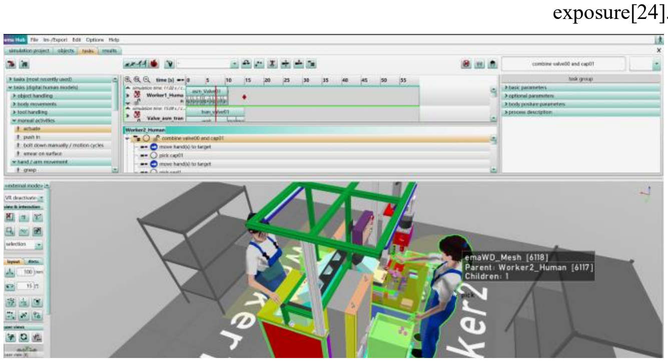

Figure 6. Establishment of Digital Human

2) Method Summary

Systematic observation methods focus on analyzing the postures of employees during actual operations, taking into account their specific conditions (such as the load they bear, grip techniques, etc.) to assess the potential risk levels. Given the variety of systematic observation methods available, selecting the appropriate one for assessing WMSDs should be based on their individual characteristics. TABLE III. summarizes the basic features of the current mainstream systematic observation methods, aiming to provide guidance for evaluators to select the most suitable method based on the specific work context.

TABLE III. BASIC CHARACTERISTICS AND APPLICATION GROUPS OF SEVEN SUBJECTIVE JUDGMENT METHODS

Method	**characteristics**	**application groups**
PLIBEL	Suitable for various work environments, especially those involving frequent movements, high-intensity physical activities, or requiring prolonged maintenance of specific postures	Clothing company operator[25]
NIOSH Lifting Equation	Suitable for material handling tasks	The elderly[26]
BRIEF	On the basis of comprehensive consideration of homework posture, checks on strength, duration, and frequency have been added	Dentist[27]
RULA	Mainly used in work environments where limb movements are the main focus	Dentist[28]
OWAS	There are relatively few evaluation areas, which is suitable for movements with less precision work and body postures with less external force	Surgeons[29]
REBA	Suitable for projects that require full body work	Embroidery worker [30]
QEC	The method of combining observer evaluation with worker self-assessment has acceptable reliability, high sensitivity, and applicability	Batik worker[31]
MFA	Focusing on measuring the accumulated fatigue level of workers	Road paving machine operator[32]
OCRA	Suitable for repetitive upper limb workers	Industrial worker[33]
EAWS	Assess the risk value of work within a work cycle	Forging staff[34]

Although systematic observation methods offer objectivity and repeatability, they have certain limitations. Their accuracy often depends on the observer’s experience and skills, and a lack of standardized criteria may lead to biased results. While these methods focus on employees' postures, actions, and work environments, they fail to capture subjective experiences such as pain, fatigue, and mental strain, leading to potentially incomplete assessments. Additionally, their limited ability to record dynamic changes makes it difficult to identify short-term or sporadic risks.

III. CONCLUSIONS

In the context of Industry 5.0, the widespread adoption of human-machine collaboration has made WMSDs a prominent issue in modern work environments. These disorders not only threaten workers' health but also directly impact work efficiency, company operating costs, and even social productivity. Therefore, exploring effective prevention and management strategies is crucial for enhancing the overall health level of industrial environments.

In this context, this paper systematically summarizes the commonly used methods for WMSDs assessment, which are mainly divided into three categories: subjective judgment methods, systematic observation methods, and direct measurement methods. Given the high cost, complexity, and interference with natural working conditions associated with direct measurement methods, their practical application is limited. As a result, subjective judgment and systematic observation methods have become more widely adopted. This paper provides an in-depth analysis of the diversity of these two methods and discusses their practical applications across various sectors such as agriculture, manufacturing, and healthcare, emphasizing the importance of selecting the appropriate evaluation tools based on specific work scenarios and assessment needs.

Driven by Industry 5.0, the introduction of digital twin technology and the concept of the digital human has brought revolutionary changes to the assessment and management of WMSDs. The digital twin models can simulate and analyze the digital human's state in various work environments, enabling more accurate prediction and management of WMSDs risks. The application of this innovative technology provides strong support for the human-centered design of work environments, laying a solid foundation for building a safe, healthy, and efficient future industrial environment.

In summary, through a systematic review and analysis of WMSDs assessment methods, this paper not only deepens the understanding of this health issue but also provides practical and feasible reference for prevention and management in real workplaces. On the theoretical level, the study enriches the academic system in the field of WMSDs assessment by systematically summarizing the applicability and limitations of evaluation methods. On the practical level, the conclusions of this paper offer clear guidance for health management practices in various industries and job roles, helping to promote sustainable development in enterprises and achieve a more intelligent and healthy work environment in the era of Industry 5.0.

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