Malaysian Journal of Ergonomics 2026, Vol 8. Issue 1: 63 - 74

A Conceptual Ergonomic Study on Upper Body Extremities of Female Operators in Composite Manual Hand Layup in the Aviation Industry

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Date Received: 11 May 2026, Date Revised: 13 June 2026, Date Accepted: 27 June 2026
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ABSTRACT

This conceptual paper explores the ergonomic challenges faced by female operators performing manual hand layup tasks in the Malaysian aviation industry. Despite the significant anthropometric differences between genders, workstations and tools in this male-dominated sector often remain standardized. This study proposes a multi-methodological framework to evaluate the risk of musculoskeletal disorders (MSDs) specifically in the upper body extremities. The proposed approach integrates subjective assessments, such as the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ), with objective postural analysis tools (RULA and REBA) and physiological measurements using surface Electromyography (sEMG). The expected outcomes of this study include the identification of specific postural risks and the correlation between physical repetitive work and mental workload. Ultimately, this research aims to provide a theoretical foundation for gender-specific ergonomic interventions, enhancing the safety, comfort, and productivity of female operators in composite manufacturing.

Keywords: Hand Layup, Composites, Aviation, Musculoskeletal Disorders, Upper Body Extremities, Mental Workload.

1. INTRODUCTION

1.1 Composite manufacturing

Nowadays, composite manufacturing is one of the most important sectors. Composite materials are used in the manufacturing process to support a variety of industries such as aircraft, ship building, automotive, civil infrastructure, household appliances, etc. A composite material is a combination of high-strength carrying-load components integrated into a low-strength material created by layering two or more composing elements with distinct chemical or physical properties and merging them to form new properties. As a result, it possesses superior characteristics, including strong stiffness, outstanding shear properties, and low density (Maria, 2013).

1.2 Laying technique of composite

Two kinds of common techniques for laying the composite materials have been applied in this industry. There are automated machines and hand layup manually. Automated Tape Laying (ATL) and Automated Fibre Placement (AFP) are two types of automated machines seen to be favourite choices and widely adopted in manufacturing environments as massive primary structure because of their great benefits (Ward et al., 2011). However, automation is not extensively utilized in composite manufacturing in Malaysia due to variations in production demands. Among them is a substantial initial investment in automated machinery, the price of which is determined

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by the automated system's complexity degree; automation machining leads to higher costs and requires more skilled operators (Rayme (b) et al., 2018). Therefore, the manual hand layup technique is still used to manufacture the products. Nonetheless, operators must equip knowledge and skills in the manual process laying technique first. One of the most well-cited studies on industrial ergonomics (Cutkosky & Wright, 1986), highlights the necessity of first understanding a manual process before modifying or changing it (Elkington et al., 2015).

1.3 Manual hand layup

Manual hand layup is a process where individual layers of carbon-reinforced composite plies known as prepreg are manually laid down. Each ply is hand-manipulated into shape before being firmly adhered to the previous layer or laminating mould surface, without air pocket between plies requiring an operator's expertise and experience to form the flat plies into complicated shapes (Elkington et al., 2015; Rayme (b) et al., 2018). This process is done repeatedly until completely forming the product structures.

When performing the manual hand layup activities, operators are requested to be in certain working postures such as bending, squatting, outreaching, etc., where they are not at the neutral posture or other word is awkward postures. This condition will contribute to their ergonomics issues. Furthermore, they are also doing the repetitive movements' task during the manual layup activities. Repetitive movement is considered one of the ergonomics risk factors which is may contribute to operators' occupational health problems. The term repetitive movements refers to tasks that are repeated with similar work cycles, over and over (Kilbom, 1994), meanwhile work cycle refers to the complete sequence of events in a task within the cycle time.

1.4 Ergonomics

Ergonomics is the study of work that uses techniques, methods, and scientific data collected from many disciplines to create engineering systems that can interact well with humans. The basic disciplines are applied physical anthropometry, physiology, psychology, cognitive science, biomechanics, and industrial systems engineering (Kroemer, K.H., Kroemer, H.B., Kroemer-Elbert, 2001). In the Handbook of Human Factor and Ergonomics 4th edition (Handbook of Human Factors and Ergonomics - Fourth Edition (2012), the term ergonomics also encompasses technology or environment, philosophy, theory, design, management, practice and education (Kamat et al., 2017). Physical ergonomics, cognitive ergonomics, and organizational ergonomics are the three most commonly referenced domains in ergonomics (Handbook of Human Factors and Ergonomics - Fourth Edition," 2012). Physical ergonomics covers the anthropometric, anatomical, physiological, and biomechanical features of humans. Cognitive ergonomics is about memory, assumption, reasoning, and motor responses involved in the mental processes that affect the interactions between humans and other system components. Meanwhile, organizational ergonomics is concerned with optimizing sociotechnical systems, such as structure, policies, and procedures. These three main domains of ergonomics are critical in ensuring that working conditions are always safe and healthy.

1.5 Ergonomics Risk and Risk Factors

The actual potential for harm or injury that may result from the presence of one or more ergonomic risk factors is referred to as ergonomic risk. The manual hand layup activities in composite manufacturing is faced with ergonomic risk factors, according to a previous study conducted by N. S. Rayme et al. (Rayme (b) et al., 2018). By referring to Mat Rebi Abdul Rani (2003) in the study done by Jaafar et al. (Jaffar et al., 2011), stated that the meaning of ergonomic risk factors are the circumstances that exist or have been created, either deliberately or inadvertently, that may or may not be harmful to operators' health and well-being at work or after work, and that may or could lead to results that are contrary to ergonomic principles.

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Repetitive movement, static posture, awkward posture, forceful exertion, hand-arm and whole body vibration, contact stress, and environmental risk factors (noise, extreme temperature, lighting, and ventilation) are the ergonomic risk factors. The operators might get musculoskeletal disorders (MSDs) if these ergonomic risk factors are not managed appropriately. As a response, ergonomic risk factors should be prioritized in efforts to protect operators safe from MSDs.

1.6 Musculoskeletal disorders

MSDs are a group of inflammatory and degenerative diseases affecting the musculoskeletal system of the human body, including muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels. The previously described structures include sprains, strains, rips, soreness, discomfort, carpal tunnel syndrome, hernias, and connective tissue injuries (Punnett & Wegman, 2004). MSDs are among the most common occupational diseases, according to the International Labor Organization (2015), accounting for 40% of all compensation expenses for work-related injuries and disorders worldwide (Márquez Gómez, 2020). MSDs can occur in the neck, shoulders, lower back, knee joints (Akhtar et al., 2022), upper back, and even the upper body if preventive measures are not taken or are insufficient.

1.7 Upper body extremities

It is also recognized as the upper limb, which consists of the shoulder girdle, the upper arm, the forearm, the wrist, and the hand. In the work environment from the past to the present, almost all jobs use the upper extremities, even when working in a sitting position. Working continuously or not taking ergonomic issues into account has the potential to cause workers to be exposed to discomfort, fatigue, and worse, can lead to MSDs. Therefore, studies involving these body parts are very important for the well-being of workers. This paper aims to investigate upper body extremities among female operators in composite manual hand layup activities in the aviation industry.

2. LITERATURE REVIEW

2.1 Previous studies in industries related to ergonomic risk factors and upper body extremities

Many ergonomic studies have been carried out in various job sectors. It is included in the manufacturing industry, construction, agriculture, animal husbandry, and other sectors in order to identify factors that contribute to MSDs in the body parts of workers.

Research conducted by Arifuddin et al. (2025) on concrete work and wall installation revealed a substantial correlation between MSDs claims and the ergonomic risks encountered by workers. They are exposed to ergonomic risk factors where they perform work in awkward postures, repetitive motion, forceful exertion, contact stress, etc. The most prevalent complaints of MSDs are back pain at 90.63%, followed by right upper arm discomfort at 84.38%. Simultaneously, the lowest incidence of MSDs complaints was attributed to left foot pain, recorded at 21.88%. This situation worsens if the workers perform their work for an extended period than usual or are in an awkward position while performing the task (Mishra et al., 2024).

This statement is also supported by the current literature on surgeons in human medicine, providing evidence that surgeons often work in awkward positions for long periods, indicating that there are significant physical ergonomic risk factors associated with the work demands of the role (Villarreal et al., 2023). Similarly, the results of a study conducted on flight cabin crew found that longer flight duration is also a contributing factor to MSDs (Akhtar et al., 2022). Additionally, a study conducted by Mahajan et al. (2023) also showed that prolonged work in the same position is a substantial risk factor for MSDs. It seems that being exposed to both ergonomic

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risk factors and long work hours has an effect on musculoskeletal symptoms that is stronger than the sum of the effects of the two factors alone (Park et al., 2022).

Repetitive work is one of the ergonomic risk factors in most workplaces. It refers to tasks that are repeatedly executed with the same work cycles (Kilbom, 1994), while the term "work cycle" means the entire sequence of events that occur within a task during its cycle time. This ergonomic risk factor can cause workers to feel uncomfortable, fatigued, and even in pain if no preventive measures are taken. A study conducted by Paskarini et al. (2025) on pottery crafting activities, which entail repetitive work, revealed that ergonomic risk factors influenced both work fatigue and well-being. In addition, poor repetitive work has been identified as one of the causes of MSDs (Akhtar et al., 2022; Mahajan et al., 2023). Another ergonomic risk factor identified as a contributor to MSDs is awkward posture (Acar & Acimis, 2023; Akhtar et al., 2022; Escobar Zabala et al., 2024; Hancharoenkul et al., 2025; Mahajan et al., 2023; Mishra et al., 2024; Nadirah Yusuf et al., 2024; Radin Umar et al., 2025; Villarreal et al., 2023; Vosoughi et al., 2024)

A study by Hancharoenkul et al. (2025) found that working in this awkward posture affects the upper body extremities among poultry slaughter workers. In the meantime, a study was done by Vosoughi et al. (2024) in the dairy industry that discovered a substantial statistical correlation between chronic fatigue and awkward posture, as well as a considerable positive correlation between MSDs and chronic fatigue. The same goes for studies on metal sculpture workers (Mishra et al., 2024), food manufacturing workers (Nadirah Yusuf et al., 2024), surgeons (Villarreal et al., 2023), office workers (Mahajan et al., 2023), and cabin crew (Akhtar et al., 2022), where they are required to perform in an awkward body posture based on their job scope, which is a potential risk of MSDs.

The studies also found that there are other factors contributing to the potential risk of MSDs. They are age (Hancharoenkul et al., 2025; Ramlee et al., 2024; Yoo et al., 2024), weight (Mahajan et al., 2023; Villarreal et al., 2023), job factors (Hancharoenkul et al., 2025; Mishra et al., 2024; Mohd Nizan et al., 2024), duration of service (Ramlee et al., 2024), noise exposure, mental and physical workload (Mokhtarinia et al., 2024), knowledge (Escobar Zabala et al., 2024), lack of ergonomics training (Vosoughi et al., 2024), work demands of the role (Villarreal et al., 2023), and gender (Acar & Acimis, 2023; Azadchehr et al., 2023; Bak et al., 2019; Kraut et al., 2024; Radin Umar et al., 2025; Yoo et al., 2024). Therefore, apart from the common ergonomic risk factors, the findings of those risk factors should also be taken into account to overcome problems related to chronic fatigue or MSDs.

Among the risk factors listed above, gender should be given priority for consideration in the study. This is because there is a significant difference between male and female workers in terms of demographics and capabilities, which will be discussed later. There is no denying that previous studies have paid attention to this factor of gender (Acar & Acimis, 2023; Bak et al., 2019; Radin Umar et al., 2025; Yoo et al., 2024), but the selection of male workers as participants is seen to be more dominant. Similarly, male workers tend to be the participants more often when implementing work involving manual layup activities in Malaysia. Refer to Table 1. The selection of female workers as study participants is essential based on the previous findings, which have proven that there is a significant difference between male and female workers. Among them is the fact that female workers who exceed 48 hours per week and are classified as obese face a significantly heightened risk of developing MSDs (Mahajan et al., 2023). Additionally, female workers in specific job titles exhibit a higher incidence of carpal tunnel syndrome (CTS) compared to their male counterparts in the same job title (Kraut et al., 2024). De Quervain's tenosynovitis, an upper extremity disorder, occurs more frequently in women (Medic-Pericevic et al., 2024). Furthermore, the median muscular load for female participants ranged from 4.5% to 47.5% of their maximum voluntary contraction capacity, while for male participants, it ranged from 2.7% to 23.6% (Bak et al., 2019).

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2.2 Previous studies on the manual hand layup activities

Table 1 and 2 shows the results of past ergonomics studies on the manual hand layup activities in the simplified table. All the studies have had a substantial impact on composite manufacturing, particularly in terms of preventing workers from getting MSDs at work. However, there haven't been many of ergonomics studies on the manual hand layup activities in this sector, especially for female operators so far. There are only a few studies that do not clearly state the gender of the respondents. Overall, in most of the studies conducted previously, the gender involved as respondents were male. In addition, this table also provides a clear picture related to the objectives of each study. It will make it easier for future researchers to plan their next ergonomic studies that will contribute to a body of knowledge to bridge the gap. Furthermore, the number of samples involved with the study was also stated.

Table 1 also lists the study's methods, such as literature review, observation, survey, and interview. Most of these studies have used the Rapid Upper Limb Assessment (RULA) as an instrument to obtain information related to the operator's body discomforts and have been analysed using software by Computer-Aided Three-Dimensional Interactive Application (CATIA) versions V5R20 and V5R21. Meanwhile, the Borg scale is an instrument that has been used to determine a person's effort, as well as shortness of breath and fatigue when performing physical tasks. At the same time, Surface Electromyography (sEMG) is a non-invasive method used to investigate muscle activation and fatigue that allows for continuous monitoring. In a study to get the size body dimensions of operators, tools like large and small anthropometer, human measuring tape (for circumference), ruler, measuring tape, and weighing scale has been used. Meanwhile, Table 2 shows the findings from the same previous ergonomics studies on manual hand layup activities in composite manufacturing.

2.3 The relationship between physical activity and the symptoms of MSDs

Figure 1 shows the relationship between physical activities and the symptoms of MSDs. It has been known from the previous literature review that there is a relationship between repetitive work, awkward posture, forceful exertion, contact stress, static posture, and vibration, which are ergonomic risk factors, with symptoms of MSDs (Mishra et al., 2024; Paskarini et al., 2025). Ergonomic risk factors occur when performing physical activities or tasks.

Previous research highlights a significant population gap, as several sub-populations remain unstudied. Regarding the physical demands of specific tasks, the female demographic warrants focused investigation, as gender-specific research in this area is notably scarce within the Malaysian context. Historically, studies have predominantly focused on male-dominated groups (Miles, 2017). However, Malaysian males and females exhibit distinct anthropometric measurements and body dimensions. This is supported by Abd Rahman et al. (2018), whose findings revealed significant differences in the mean dimensions between the two genders. Based on this justification for selecting female operators, Hypothesis 1 (H1) posits that a significant relationship exists between physical activities and musculoskeletal disorder (MSD) symptoms in the upper body extremities of workers performing manual hand layup tasks in the aviation industry.

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Table 1. Previous ergonomics studies on the manual hand layup activities in composite manufacturing (Yusof et al., 2023)

Reference	Objective	Sample (N)	Method(s)
(Rayme (a) et al., 2018)	To identify potential respondents for an experimental ergonomics study on composite manufacturing's manual hand layup operators.	i) Preliminary survey: A total of operators in manual layup department (N is confidential). ii) Experimental: N=12 of 28 (male) - Body Measurement Index (BMI) and discomfort experience level as references to be selected.	i) Literature studies. ii) Observation. iii) Interview iv) Survey: - Nordic Musculoskeletal Questionnaire (NMQ). - Rapid Upper Limb Analysis (RULA) analyzed by Computer-Aided Three-Dimensional Interactive Application (CATIA) V5R21 software.
(Rayme (b) et al., 2018)	To examine the operators' work posture and their feelings of discomfort in the manual hand layup process department.	i) Preliminary survey: N = 45 from manual layup department	i) Literature studies. ii) Observation. iii) Interview. iv) Survey: - Borg's scale. - RULA analyzed by CATIA V5R20 software.
(Rayme (c) et al., 2018)	To investigate the anthropometry data gap and inaccuracy in Malaysian industrial operators in comparison to Japanese and American populations in Digital Enterprise Lean Manufacturing Interactive Application (DELMIA) V5R2016	i) Operators involved: N = 241(male)	i) Measuring size body dimensions by using anthropometry measuring tools (large and small anthropometer, human measuring tape {for circumference}, ruler, measuring tape, and weighing scale).
(Rayme (d) et al., 2018)	To examine the manual hand layup activities that affected the operators' heart rate (HR) in composite manufacturing.	i) Estimated operators: N = maximum 1 day are 10 / one-hour session	i) Microcomputer. ii)Reliability of data set iii) Equipment for calibrations.
(Azizan et al., 2018)	To investigate the operators' heart rate (HR) and muscle activity affected muscle fatigue in composite manufacturing.	i) Preliminary survey: N = 31 (male) ii) HR Analysis: N = 10 of 31(male) iii) Muscle activity analysis: N = 2 of 31(male)	i) Survey: - NMQ. ii) HR Analysis: - Wristwatch with a chest strap. iii) Muscle activity: - Surface Electromyography (sEMG). iv) Perception of stress: - Perceived stress scale.
(Kamat et al., 2016)	To reduce the maximum effort level of operators' lumbar muscles by changing proper anthropometry of operators for the height of the workstation.	i) Preliminary survey: N = 22 (male). ii) Experimental: N = 6 (male)	i) Survey: - RULA analyzed by CATIA software. ii) Muscle activity: - sEMG. - Noraxon software.

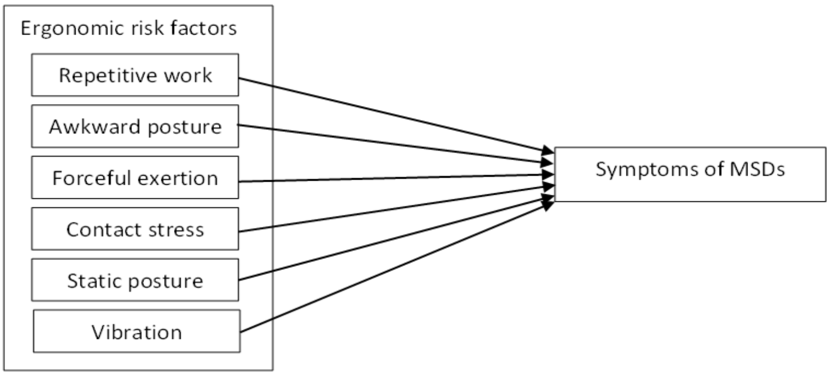

Figure 1: The relationship between physical activities and the symptoms of MSDs

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Table 2. Finding(s) of the previous ergonomics studies on the manual hand layup activities in composite manufacturing

Reference	Finding(s)
(Rayme (a) et al., 2018)	Operators' backs are the most severely affected, with workers reporting more pain in their upper and lower backs than in other areas of their bodies
(Rayme (b) et al., 2018)	83.3% of operators suffer from lower back discomfort. On a scale of 1 (lowest) to 5 (highest), 41% assessed their pain level as 4. Pain and discomfort lead to lower operator productivity, which can affect the quality of the product produce.
(Rayme (c) et al., 2018)	Several discrepancies in anthropometric parameters exist among the three population comparisons, with inaccuracies and gaps exceeding 5%.
(Rayme (d) et al., 2018)	Over 40% of operators in a Malaysian composite manufacturing exhibited a heart rate exceeding the typical resting heart rate of 62 to 78 beats per minute. The average HR of operators exceeded the normal HR level. The manual hand layup process is classified as a moderate-intensity task.
(Azizan et al., 2018)	The manual hand layup department operators' muscle fatigue was strongly correlated with their HR, which in turn affected their muscle activity.
(Kamat et al., 2016)	The results showed that anthropometry adjustments combined with an adequate workstation height decreased physiological strain, including excessive working posture and lumbar fascia muscle workload.

3. METHODOLOGY

The methodology for this conceptual study is organized into three systematic phases, beginning with a rigorous participant selection process and concluding with the integration of subjective and objective data. The initial phase focuses on Research Sampling, specifically targeting female operators within the aviation composite industry. Selection criteria are established to ensure a representative sample while controlling for confounding variables. This includes screening for pregnancy status—as it significantly alters physiological and anthropometric baselines—and evaluating body weight/BMI to determine the inclusion of individuals categorized as obese. Participant history and lifestyle factors are also documented to assess their potential influence on musculoskeletal health.

The second phase involves the application of Subjective and Observational Assessment tools to quantify postural risk and discomfort. To capture the participants' perceived symptoms of musculoskeletal disorders (MSDs), the study utilizes validated instruments such as the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) or the Nordic Musculoskeletal Questionnaire (NMQ). These subjective reports are then cross-referenced with systematic postural assessments. The Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) are employed to evaluate awkward postures in real-time. For tasks characterized by high-frequency repetition, the Assessment of Repetitive Tasks (ART) and Occupational Repetitive Action (OCRA) tools provide a specialized analysis of repetitive strain on the upper extremities.

The final phase consists of Physiological Measurement and Data Synthesis to provide an objective layer to the conceptual framework. The study proposes the use of surface Electromyography (sEMG) to monitor muscle activation and fatigue in the trapezius and forearm muscles during the manual hand layup process. By synchronizing the sEMG data with the postural scores (RULA/REBA), the researcher can identify specific points in the task where physical strain is most acute. This multi-methodological approach is designed to fulfill the research objectives by establishing a clear correlation between the physical demands of the task and the resulting MSD symptoms, ultimately providing a basis for gender-specific ergonomic redesign in the aviation industry.

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4. EXPECTED CONTRIBUTIONS AND OUTCOMES

The proposed conceptual framework is expected to provide significant contributions to the field of industrial ergonomics, particularly within the niche of aviation manufacturing. By focusing on the female demographic in a traditionally male-oriented industry, this study addresses a critical knowledge gap. The expected contributions are categorized into theoretical advancements, practical applications, and social impacts.

4.1 Theoritical Contributions

This research is expected to refine the understanding of gender-specific ergonomic risk factors. By integrating subjective discomfort data (CMDQ/NMQ) with objective postural (RULA/REBA) and physiological (sEMG) measurements, the study will provide a holistic model for assessing upper body extremities. This integrated approach will help validate the necessity of including gender as a primary variable in ergonomic research, particularly regarding anthropometric differences in the Malaysian context. Furthermore, the framework aims to clarify the relationship between physical repetitive strain and mental workload, contributing to a more comprehensive theory of worker fatigue.

4.2 Practical and Methodological Outcomes

The study intends to yield a systematic assessment protocol that can be utilized by safety officers and ergonomic practitioners in the aviation industry. Expected outcomes include the identification of high-risk stages within the manual hand layup process that are most likely to cause MSD symptoms in female operators. These insights will provide a data-driven basis for recommending workstation redesigns, such as adjustable table heights, modified tool grips, or optimized task rotation schedules tailored to the female anthropometric profile.

4.3 Social and Organizational Impact

Beyond technical metrics, this study is expected to promote a more inclusive and safer work environment. By addressing the physical health of female operators, the proposed research aims to reduce the long-term prevalence of MSDs, thereby decreasing medical costs and absenteeism while increasing job satisfaction. The findings are expected to serve as a guideline for Malaysian aviation companies to develop internal ergonomic policies that support a diverse workforce, ultimately enhancing the industry's overall productivity and global competitiveness.

5. CONCLUSION

In conclusion, this conceptual study highlights the critical need for gender-specific ergonomic assessments within the Malaysian aviation industry. By focusing on the unique anthropometric profiles and physiological requirements of female operators, the proposed research addresses a significant gap in current manual hand layup literature. The integration of subjective discomfort surveys, systematic postural analysis, and objective muscle activity measurement via sEMG provides a robust framework for identifying risks to the upper body extremities. While the scope of this investigation is currently limited to repetitive work due to resource and time constraints, it establishes a vital foundation for future empirical research. Ultimately, the successful implementation of this framework is expected to facilitate the design of more inclusive, safe, and productive work environments, ensuring that ergonomic interventions are effectively tailored to the diversity of the modern workforce.

ACKNOWLEDGEMENTS

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