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Posture Assessment of Rubber Tappers: A Comparative Analysis of OWAS, REBA, RULA, and PERA Methods

Abi Varghese[1,2], Vinay V. Panicker[1,*], Joby George[2]

[1]Industrial Engineering Laboratory, Department of Mechanical Engineering, National Institute of Technology Calicut, Kerala, India
[2]Department of Mechanical Engineering, Amal Jyothi College of Engineering, Kottayam, Kerala, India

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Abstract

Background: *The study provides a comprehensive ergonomics assessment of the postures encountered by rubber tappers using the OWAS, REBA, RULA, and PERA methods and compares the risk levels across various ergonomic assessment methodologies.* **Methods:** *The research examines the postures of fifty-one selected rubber tappers from the state of Kerala, India, during rubber tapping, analyzing 1111 different working postures. The postural assessment was conducted by analyzing video recordings of the work tasks and evaluating the postures using OWAS, REBA, RULA, and PERA. Each method's focus and application were considered to comprehensively evaluate the postural risks.* **Results:** *The demographic characteristics indicate that the workforce mostly consists of middle-aged males involved in physically strenuous activities. The result shows that the RULA method, emphasizing upper limb postures, is particularly suited for assessing postural loads in rubber tapping, highlighting the need to match ergonomic tools to the specific demands of work activities. While OWAS provides a general overview, RULA focuses on upper limbs, REBA assesses whole-body postures, and PERA incorporates cyclic work factors, enabling targeted ergonomic interventions. Additionally, it is crucial to consider that each method OWAS, RULA, REBA, and PERA has distinct strengths and applications.* **Conclusions:** *The research highlights the need for tailored ergonomic interventions for tasks such as 'Incision on the Channel'. Ultimately, the study validates implementing a context-specific approach for assessing ergonomic parameters and intervention measures aimed at enhancing the overall occupational health of rubber tappers.*

1. Introduction

In many Asian countries, such as Thailand, Indonesia, Vietnam, China, and India, rubber tapping is one of the most skilled agricultural occupations [1]. It involves making incisions in the bark of the rubber tree trunk in a downward spiral form. Most workers consider rubber tapping a secondary occupation [2]. As a result, many complete the tapping early in the morning and start their primary job during the day. Moreover, rubber tapping in the predawn hours provides maximum yield [3]. Consequently, the working characteristics of rubber tappers are unique, involving precision work, uneven terrains, poor climatic conditions, early working hours, fear, and repetitive tasks. These conditions can adversely affect the workers' physical and mental health.

Musculoskeletal disorders (MSDs) are among the most common physical occupational hazards faced by rubber tappers [4]. Identifying awkward postures and implementing appropriate working postures can improve both the MSDs and the productivity of the workers [5-7]. The following assessment methods are used to identify MSDs [8]:

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*Corresponding Author: Vinay V. Panicker; E.mail: vinay@nitc.ac.in

- Self-report study;
- Observational methods;
- Direct measurement method.

The self-reported study is the most commonly used assessment method because it can be applied in various working situations, obtaining large samples at low cost and with minimal time investment. However, the accuracy of the data collected from the subjects is low [9]. For high precision and lower subjectivity, the observational method is the best assessment method for postural analysis [10]. Some of the observational methods used for postural assessment include:

- *Ovako Working Posture Analysis System (OWAS):* Focuses on the back, arms, and legs, assessing general postural risks without considering the duration or force exerted [11];
- *Ergonomic Workplace Analysis (EWA):* Evaluates overall workplace ergonomics, focusing on posture, movements, and workstation design to improve working conditions and prevent musculoskeletal disorders [12];
- *Ergonomics Checklist:* Evaluates various factors such as body posture, movement, and workstation design to prevent musculoskeletal disorders [13];
- *Rapid Upper Limb Assessment (RULA):* Targets upper limb postures, including the neck, trunk, and arms, making it particularly sensitive to tasks involving significant upper limb activity [14];
- NIOSH Lifting Equation: Assess the safety of manual lifting tasks by calculating the recommended weight limit based on the load's weight, horizontal and vertical position, distance moved, frequency of lifting, and grip quality to minimize the risk of lifting-related injuries. [15];
- *PLIBEL Checklist*: Focuses on identifying potential hazards in the workplace related to physical load, such as posture, repetitive movements, and manual handling [16];
- *Strain Index:* Evaluate the risk of developing upper extremity musculoskeletal disorders by assessing task-related factors such as intensity, duration, and frequency of exertion, along with wrist posture, speed of work, and duration of task per day [17];
- *Occupational Repetitive Actions (OCRA)*: Assess the repetitive tasks by analyzing factors such as the frequency of actions, force exerted, awkward postures, and recovery periods to ensure workplace safety and ergonomics [18];
- *4D Watback:* Evaluate manual handling tasks by analyzing dynamic movements in four dimensions (spatial and temporal) to prevent work-related musculoskeletal disorders and enhance safety [19];
- *Rapid Entire Body Assessment (REBA):* Evaluates whole-body postures, including the neck, trunk, upper limbs, and lower limbs, and considers postural angles, forceful exertions, and the nature of movements [20];
- *Loading on the Upper Body Assessment (LUBA):* Evaluate the load and posture of the upper body during work tasks, focusing on the arms, shoulders, neck, and back to identify and mitigate potential risks [21];
- *Upper Limb Risk Assessment (ULRA):* Evaluate the upper limbs by assessing factors such as repetitive movements, force exertion, awkward postures, and duration of tasks [22];
- *Quick Exposure Check (QEC):* Identify ergonomic risks for musculoskeletal disorders by evaluating exposure to risk factors in specific work tasks [23];
- *Assessment of Repetitive Tasks (ART):* Evaluate the risk of upper limb disorders associated with repetitive work by analyzing factors such as repetition, force, awkward postures, and additional factors like vibration and breaks [24];
- *Agricultural Lower Limb Assessment (ALLA):* Evaluate the risk of musculoskeletal disorders in the lower limbs of agricultural workers by analyzing factors such as repetitive movements, force exertion, awkward postures, and duration of tasks [25];
- *Agricultural Upper Limb Assessment (AULA):* Evaluate the risk of musculoskeletal disorders in the upper limbs of agricultural workers by

assessing repetitive movements, force exertion, awkward postures, and the duration of tasks [26];
- *Hand Arm Risk Assessment Method (HARM):* Evaluate the risk of musculoskeletal disorders and other injuries to the hands and arms by analyzing factors such as repetitive motions, force exertion, posture, and vibration exposure [27];
- *Novel Ergonomic Postural Assessment (NERPA):* Assess work postures using a digital human model and 3D CAD tools to identify ergonomic risks and optimize workplace design [28];
- *Agricultural Whole-Body Assessment (AWBA):* Evaluate the risk of musculoskeletal disorders in agricultural workers by analyzing whole-body postures, repetitive movements, force exertion, and task duration [29];
- *Postural Ergonomic Risk Assessment (PERA*): Assesses cyclic work by considering posture, duration, and force across the entire work cycle, providing a comprehensive risk assessment [30].

Some researchers have conducted comparative studies of various postural assessment methods. Kee et al. calculated the maximum holding time in different body postures and compared it with OWAS, RULA, and REBA. The results indicate that RULA is the most effective posture assessment tool for postural load [31]. A similar study based on self-reported discomfort surveys yielded comparable results [32]. Choi et al. compared AULA with OWAS, RULA, and REBA across 196 tasks involved in various farming operations [33]. Another study was carried out among farm workers, evaluating 196 working postures using OWAS, RULA, and REBA [34]. Further research investigated various stages of timber harvesting, such as logging, skidding, and loading, comparing the postural assessments using OWAS and REBA [35]. Micheletti et al. assessed and compared the different postures of the operator during the manual feeding of a wood chipper using RULA and REBA [36]. Zare et al. presented self-report studies, observational methods, and direct measurement techniques in a truck assembly unit for upper limb and back assessments [37]. Chiasson et al. examined eight distinct assessment tools, including QEC, FIOH, RULA, REBA, JSI, HAL, OCRA, and EN 1005-3, while evaluating 567 tasks within the industrial sector [38].

The literature review shows that OWAS, RULA, and REBA are commonly used postural assessment tools [39]. The Postural Ergonomic Risk Assessment (PERA) is a newly developed posture assessment tool used to evaluate cyclic work [30]. Rubber tapping is a physically demanding activity that involves repetitive movements and sustained awkward postures. Each method focuses on different aspects of postural assessment, which can lead to variations in their output scores. For instance, the RULA method emphasizes the upper limbs, which can result in higher postural load scores if these body parts are predominantly involved in the task [40]. This paper aims to compare these methods in the context of rubber tapping to identify the most appropriate tool for assessing postural load and risk. Hence, the objectives of this research are as follows:

- Evaluate the risk factors among rubber-tapping workers through a self-reported questionnaire and observational methods in real practice;
- Compare the posture assessments of rubber-tapping workers to analyze the convergence of the OWAS, RULA, REBA, and PERA observational methods;
- Identify the suitability of various ergonomic assessment methods for identifying postural risks among rubber-tapping workers.

2. Methods

2.1. Study Population

A cross-sectional study was conducted among rubber-tapping workers in Kerala, a state in India, known as one of the world's leading natural rubber producers [1]. Fifty-one rubber-tapping workers were selected for the study after being informed about its objectives and the methods used for data collection. Participants provided their oral consent before data collection began. The criteria for participant selection included: (a) being a regular rubber tapper; (b) having at least one year of experience in rubber tapping; and (c) being at least eighteen years old. The study comprised 48 male and 3 female rubber tappers. Both demographic information and posture assessments covered the entire participant group, including male and female workers.

Various postures of fifty-one rubber tappers from videos captured during rubber tapping were examined, and 1,111 working postures were recommended for analysis. The detailed analysis of these 1,111 postures revealed that the majority (622 postures) were associated with the sub-task 'Incision on the Channel' suggesting this sub-task's high frequency and significance in the rubber tapping process. The distribution of the remaining postures among the other sub-tasks was as follows: 157 postures for 'Removal of Latex Cover from the Channel', 198 postures for 'Adjusting the Collecting Cup', and 134 postures for 'Moving to the Next Rubber Tree'. Most of the rubber tappers were male (48 males and 3 females), with a majority being middle-aged (46-60 years) and an average age of 51.78 (±10.94) years. The average body mass index (BMI) was 24.2 kg/m^2. Most workers (55%) were of normal weight, while a small percentage (5.8%) were underweight. Most workers had only a matriculation-level education, and many had over 30 years of experience in rubber tapping.

2.2. Data Collection Method

A questionnaire based on the Standard Nordic Questionnaire was developed for rubber-tapping workers, involving demographic details, work activity assessment, and physical and mental health assessment. Personal interviews were conducted with the rubber tappers to gather information about their work activity and demographic background. Additionally, participants were asked to assess the degree of pain or distress they experienced in various parts of their bodies during the tapping operation. To analyze the postures of rubber-tapping workers, conducted video recordings of the entire work cycle during typical rubber-tapping activities. The video recordings captured the complete range of activities performed by the rubber tappers, removing the latex cover, including making incisions, adjusting collection cups, and moving between trees. Each recording was segmented into individual frames to capture static postures at regular intervals, ensuring a comprehensive evaluation of the postural variations throughout the work cycle. From these segmented video frames, we selected 1,111 postures for detailed analysis based on criteria that included postures held for prolonged periods, involved significant force exertion, or were frequently repeated.

2.3. Observational Method

The posture assessments were conducted using various observational methods: OWAS, REBA, RULA, and PERA, by capturing frames from video recordings. Each of the four ergonomic assessment methods, this study uses distinct characteristics and application focuses. The action categories were grouped into four cluster levels to compare the results of different observational methods.

2.3.1. Ovako Working Posture Analysis System (OWAS)

OWAS, one of the oldest ergonomic assessment tools, was developed during the 1970s through collaboration between work-study engineers and Ovako Oy, a privately owned steel company in Finland [11]. It focuses on the discomfort caused by working postures to provide a framework for redesigning working conditions. OWAS primarily assesses back, arms, and leg postures without considering the duration of postures or the force exerted. The framework delineates seven limb postures, three arm postures, and four back postures and considers the weight being carried during the labor task. Video recordings of rubber-tapping tasks were captured, and specific postures were identified and segmented for analysis. Each identified posture was categorized according to the OWAS coding system, which includes back postures (straight, bent forward, twisted, or bent and twisted), arm postures (both arms below shoulder level, one arm at or above shoulder level, both arms at or above shoulder level), leg postures (standing on both legs, standing on one leg, standing with weight shifting, kneeling, or walking), and load handling (no load, handling a load less than 10 kg, handling a load more than 10 kg). OWAS divides the injury risk associated with a particular working posture into four distinct action categories:

- Cluster Level 1 (OWAS CL1): Action Category 1 – Except in a few instances, normal postures do not necessitate any particular attention;
- Cluster Level 2 (OWAS CL2): Action Category 2 – Future periodic assessments of working methods must consider postures; corrective actions will be required;
- Cluster Level 3 (OWAS CL3): Action Category 3 – In the near future, postures will require attention; corrective measures must be implemented immediately;
- Cluster Level 4 (OWAS CL4): Action Category 4 – Immediately correcting postures is required.

The OWAS method was used to categorize the postures of rubber tappers into predefined classifications according to their back, arms, and leg positions. During the observation of subtasks, the frequency and duration of each posture were recorded.

Each posture was then assigned a risk category (Action Category 1 to 4) based on the OWAS coding system. For example, bending while making incisions on the rubber tree was classified under higher risk levels due to sustained and awkward back posture.

2.3.2. Rapid Upper Limb Assessment (RULA)

RULA was developed for the rapid evaluation of body posture *during* upper extremity tasks, concentrating extensively on the upper limbs, neck, and trunk, *which makes* it especially sensitive to tasks that *involve* significant upper limb activity [14]. Conducting a postural analysis *with* RULA *entail*s assessing the angles of the wrist, lower arm, upper arm, neck, trunk, and legs, typically determined through the observation of the task, load, nature of work, and duration in the field. *The outcome* of the RULA assessment tool is the RULA Score, a sing*ular* number ranging from 1 to 7 that indicates the degree of musculoskeletal disorder (MSD) risk associated with the job task under examination. Video recordings of the rubber tapping tasks were analyzed to capture detailed upper limb postures, each of which was scored according to the RULA criteria. The scores were aggregated to determine risk levels and categorized into action levels that indicate the urgency of intervention, providing a targeted analysis of postural risks specific to upper limb activities in rubber tapping. The final scores are grouped into four cluster levels:

- Cluster Level 1 (RULA CL1): Score 1 and 2 - Minimal risk; No action is recommended;
- Cluster Level 2 (RULA CL2): Score 3 and 4 - Low risk, Change may be recommended;
- Cluster Level 3 (RULA CL3): Score 5 and 6 - Medium risk, Immediate change may be required;
- Cluster Level 4 (RULA CL4): Score 7 and more - High risk, Immediately Change required.

RULA was specifically employed to assess postures involving significant upper limb activity, which is prevalent in rubber tapping. During the subtasks, postures were analyzed in static and dynamic states, with a particular focus on the "incision" activity. Scores for arm, wrist, and neck positions were assigned based on angular measurements and load requirements. Additional adjustments were made for muscle use and static postures. The final scores categorized the risk levels, highlighting areas requiring immediate ergonomic intervention.

2.3.3. Rapid Entire Body Assessment (REBA)

REBA was developed to assess the posture of individual workers regarding MSDs and the risks associated with various tasks, evaluating the entire body, including the neck, trunk, and limbs, though it is not as comprehensive in upper limb assessment as RULA [20]. The method takes into account both upper and lower extremity postural angles, forceful exertions, the nature of movements or actions, and repetition in its analysis.

The REBA Score, which ranges from 1 to 11, indicates the degree of MSD risk linked to the job task being evaluated. In the context of rubber tapping, video recordings of the tasks were analyzed to capture a comprehensive array of postures. Each posture was scored based on REBA's criteria, which involve assessing body segment angles, the force exerted, and the nature of movements. The aggregated REBA scores offered a clear indication of overall postural risks, categorized into action levels to inform necessary interventions. This thorough application of REBA facilitated the identification of high-risk postures in rubber tapping, ensuring that suitable ergonomic measures could be implemented to reduce these risks. The final scores are grouped into four cluster levels:

- Cluster Level 1 (REBA CL1): Score 1 and 3 – Negligible risk or Low risk, No change or change may be required;
- Cluster Level 2 (REBA CL2): Score 4 and 7 – Medium risk, Change may be required soon;
- Cluster Level 3 (REBA CL3): Score 8 and 10 – High risk, Change required;
- Cluster Level 4 (REBA CL4): Score 11 and more – Very High-risk Immediate Change required.

The REBA tool was utilized to analyze whole-body movements specific to the subtasks of rubber tapping. For instance, during the "incision" subtask, detailed evaluations of trunk flexion, shoulder elevation, neck posture, and wrist deviations were performed. These observations were combined with load and coupling factors to generate a comprehensive risk score for each task. The overall risk level was calculated by summing individual scores and correlating them with predefined risk categories in the REBA framework.

2.3.4. Postural Ergonomic Risk Assessment (PERA)

PERA evaluates cyclic work by assessing the necessary force, duration of each task, and the physical posture of the workers [30]. The entire work cycle of rubber tapping is broken down into smaller tasks to swiftly identify high-risk activities and provide an overall averaged score along with recommendations for ergonomic intervention. In the context of rubber tapping, video recordings of the complete work cycle were analyzed to decompose the process into distinct tasks, such as making incisions on the channel, adjusting collection cups, and moving between trees. Each task was assessed for the exerted force, duration, and the posture adopted by the workers. The PERA method calculates an overall average score, ranging from 1 to 27, which is regarded as the final PERA score and categorized into low, medium, and high risks. The final scores are organized into four cluster levels:

- Cluster Level 1 (PERA CL1): Score 1 and 4 – Negligible risk or Low risk, No change or change may be required;
- Cluster Level 2 (PERA CL2): Score 4 and 7 – Medium risk, Change may be required soon;
- Cluster Level 3 (PERA CL3): Score 7 and 12 – High risk, Change required;
- Cluster Level 4 (PERA CL4): Score 13 and more – Very High-risk Immediate Change required.

PERA was adapted to evaluate cumulative ergonomic risks in the rubber tapping context, which differs from its traditional industrial applications. Its principles were adapted to assess the unique work dynamics of rubber tapping, which involves repetitive tasks with cyclical patterns. Work cycles were defined as the sequential execution of subtasks (e.g., removing the latex cover, making incisions on the channel, adjusting collection cups, and moving between trees). Each cycle was broken down into discrete postures, with duration and repetition recorded.

2.4. Comparison of Assessment Methods

The posture assessments were conducted using four observational methods—OWAS, REBA, RULA, and PERA— by analyzing frames captured from video recordings during the self-reported study. A two-stage evaluation process was employed to ensure the reliability and validity of these assessments. In the first stage, three experienced ergonomists independently assessed the postures using the specified methods, minimizing bias and capturing a diverse range of observations. In the second stage, three ergonomists re-evaluated the postures to verify the initial assessments. This secondary evaluation ensured consistency and accuracy in the findings. A high level of consensus (95% agreement) was observed between the two groups of ergonomists, with discrepancies being minimal and primarily related to subjective interpretations of intermediate postures. These discrepancies were resolved through discussions, ensuring that all assessments were thoroughly reviewed and agreed upon.

The final scores from the four observational techniques were categorized into four cluster levels for effective comparison. Postures were classified based on work type and tapping level, as tapping level significantly influences the incidence of musculoskeletal disorders (MSDs) [41]. The tapping levels were divided into three groups: (i) below waist level (BW), (ii) below shoulder level (BS), and (iii) above shoulder level (AS). Additionally, the entire rubber tapping process was segmented into four sub-tasks to enhance the accuracy of the posture assessment.

- Removal of Latex Cover from the Channel (Rc): This task involves carefully removing the latex cover from the tapping channel without damaging the tree bark. It requires precision and care to avoid disrupting the latex flow. Due to the precision needed to avoid bark damage and disruption of latex flow, it involved moderate levels of force. Its repetitive nature across multiple trees added to cumulative strain. The high frequency of this task within a tapping cycle made it a significant contributor to repetitive motion strain.
- Incision on the Channel (Ic): This critical task entails making precise cuts on the tapping channel to extract latex. It requires considerable skill and accuracy, as improper incisions can decrease latex yield and harm the tree. It necessitates high levels of force during precise cuts. Observations indicated increased muscular effort in the dominant arm, shoulder, and wrist. This sub-task also demands sustained accuracy postures, which contribute to muscular fatigue over time. The moderate repetition of multiple incisions per tree further exacerbates cumulative strain.
- Adjusting the Collecting Cup (Ac): This task involves positioning or adjusting the collection cups to ensure that the latex flows into them effectively. The height and placement of the cups need to be modified according to the latex flow. Depending on the amount of cup lump, it requires low to moderate force. Workers often maintained bent or squatting postures for brief periods, contributing to static loading on the lower back and knees. The high frequency of this task across several trees heightened the ergonomic risks linked to static postures.
- Moving to the Next Rubber Tree (Mt): This involves the transition of rubber tappers from one tree to another, often across uneven terrain. It requires minimal force, except when workers carry tools and exert force during transitions across uneven terrain. Although brief, the repetitive nature of this activity throughout the workday contributes to fatigue in the lower extremities due to consistent movements.

2.5. Statistical Analysis

The study evaluating the postures of rubber-tapping workers employed four observational methods: OWAS, REBA, RULA, and PERA, which assessed workers' postures during tasks. To evaluate the effectiveness of these methods, bar charts were created to compare postural loads. A thorough statistical analysis indicated that the postural assessment scores showed a skewness value of -0.239, suggesting a non-normal distribution. Therefore, non-parametric tests were utilized instead of standard parametric tests.

The primary statistical analysis utilized was the Wilcoxon signed-rank test, which is suitable for non-parametric data commonly found in posture assessment. This test evaluated statistically significant differences in mean ranks of risk levels from the four methods. By pairing the four assessment methods (a total of six pairs), the mean risk levels were compared to identify any significant differences, facilitating direct comparisons of risk levels. The Wilcoxon test's independence from the normal distribution assumption made it particularly fitting for this analysis.

3. Results and Discussion

3.1. Work Activity Assessment

Many workers view rubber tapping as a secondary job. As a result, they start this work early in the morning before heading to their primary employment. These primary roles include physically demanding tasks such as agriculture, loading and unloading, and masonry, as well as less strenuous activities like office work, running a business, and driving. Nearly half of the workforce participates in physically demanding jobs for 5 to 8 hours daily. All workers are right-handed except for one person. About half of the rubber tappers manage 200 to 300 trees in a single shift; most work more than five days a week. Rubber tappers operate in lowland and highland areas, with highland locations being more common. Another factor that influences posture is the age of the trees; 60% of rubber tappers tap trees between 9 and 12 years old.

3.2. Posture Assessment Based on the Work Type

The 'Work Type' involved in rubber tapping is divided into four categories: (i) Removal of Latex Cover from the Channel, (ii) Incision on the Channel, (iii) Adjusting the Collecting Cup, and (iv) Moving to the Next Rubber Tree. Most postures belong to 'Incision on the Channel' (56.16%), as shown in Figure 1.

This finding emphasizes the various and delicate movements required for this particular task. Conversely, the work type 'Moving to the Next Rubber Tree' exhibits a substantially lower number of postures. The research highlights the significance of identifying specific types of work and corresponding body postures to tackle potential ergonomic issues and improve workers' overall health and comfort. The prevalence of postures in 'Incision on the Channel' underscores the necessity for customized interventions targeting ergonomic issues related to rubber tapping.

3.3. Posture Assessment Based on the Level of Tapping

The results in Figure 2 provide valuable insights into the distribution of recommended postures among rubber tappers based on different levels of tapping. The tapping levels are categorized into three groups: Below Waist Level (BW), Below Shoulder Level (BS), and Above Shoulder Level (AS). Notably, more than half of the postures (65.34%) fall within the 'Below Shoulder Level' category because regular tapping of rubber trees begins when the trunk attains a girth of 50 cm around a tree height of 100 cm from the ground. This finding underscores the significance of the mid-level range in ergonomic considerations for rubber tapping activities. The high prevalence of postures in the 'Below Shoulder Level' category indicates that most of the recommended movements required for effective rubber tapping are situated between the waist and shoulder height. This critical observation informs ergonomic interventions, suggesting a focus on addressing challenges and optimizing conditions in the mid-level range to enhance the overall working experience and health of rubber tappers.

3.4. Comparison Based on Risk Levels

3.4.1. RULA vs OWAS

The OWAS cluster levels are shown in Figure 3(a). Out of 1,111 postures, RULA and OWAS cluster levels matched for 245 positions (27 in level 2, 61 in level 3, and 157 in level 4), while 866 postures demonstrated differing levels. The agreement degree between OWAS and RULA was approximately 22.05%. Among the 866 postures lacking consensus, OWAS overestimated 53 and underestimated 813 compared to RULA. Table 1 shows that 438 postures had a one-level difference, 289 had a two-level difference, and 139 had a three-level difference. Statistical tests confirm that OWAS tends to underestimate; the Wilcoxon signed-rank test indicates RULA scores for postural load are significantly higher than OWAS ($p < 0.01$).

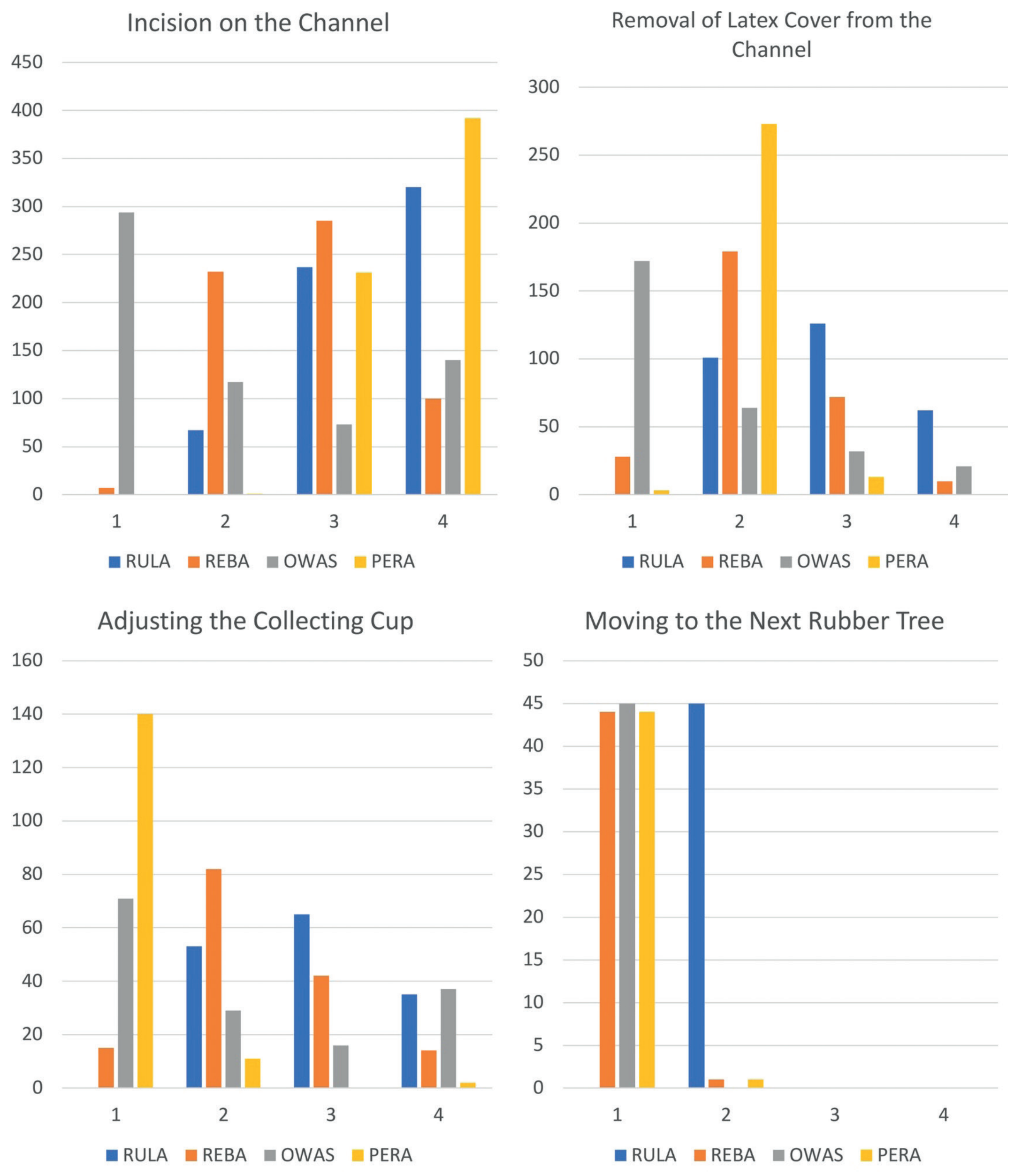

Figure 1. Cluster Level Distribution Based on Work Type.

3.4.2. RULA vs REBA

The relationship between REBA and RULA cluster levels is depicted in Figure 3(b). Of 1,111 postures, 432 had identical cluster levels (174 in level 2, 136 in level 3, and 122 in level 4), while 679 showed distinct levels. The concurrence level was around 38.88%. Among the 679 differing postures, REBA underestimated 674 and overestimated 5 compared to RULA. Table 1 indicates 639 postures differed by one risk level, and 40 by two levels. The Wilcoxon signed-rank test results confirm REBA's underestimation; RULA scores are statistically higher ($p < 0.01$).

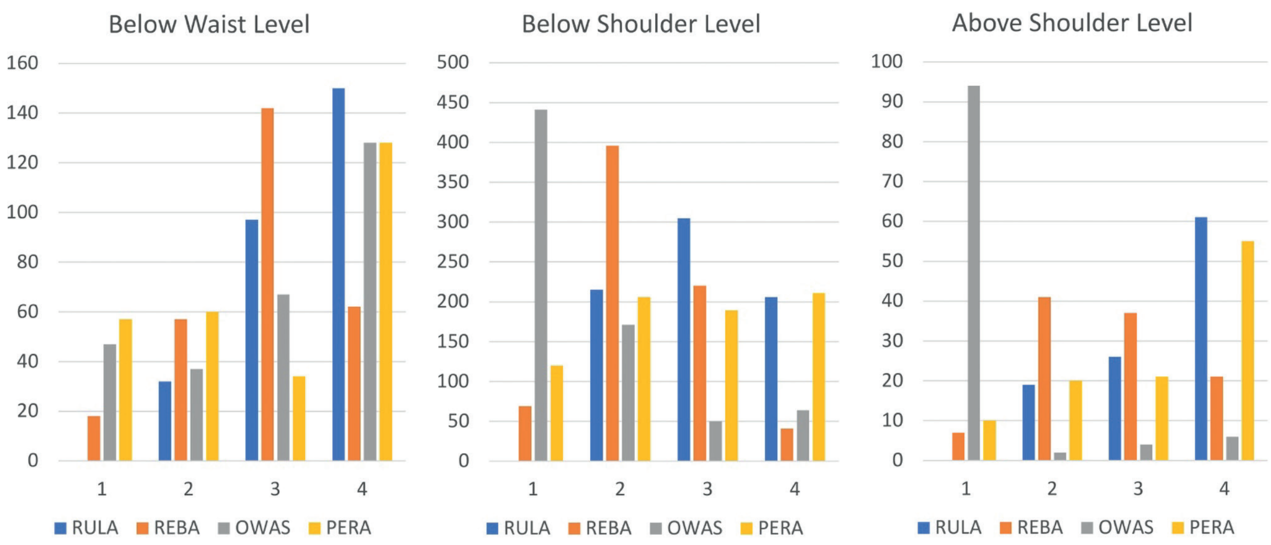

Figure 2. Cluster Level Distribution Based on Level of Tapping.

3.4.3. RULA vs PERA

Figure 3(c) illustrates the relationship between PERA and RULA cluster levels. About 543 postures had matching cluster levels (100 in level 2, 148 in level 3, and 295 in level 4), while 568 had distinct levels. The concurrence level between RULA and PERA was 48.88%. Among the 568 differing postures, PERA overestimated 164 and underestimated 404 compared to RULA. According to Table 1, 416 postures had a one-level difference, 119 had a two-level difference, and 33 had a three-level difference. The Wilcoxon signed-rank test results show that RULA scores for postural load are statistically higher than PERA ($p < 0.01$).

3.4.4. REBA vs OWAS

Figure 4(a) compares cluster levels of OWAS and REBA. Out of 1,111 postures, 355 had matching cluster levels (89 in level 1, 111 in level 2, 77 in level 3, and 78 in level 4), while 756 showed distinct levels, yielding an agreement of about 31.95%. OWAS underestimated 589 postures and overestimated 167 among the 756 misaligned cases. Differences were noted, with one risk level in 582 postures, two in 148, and three in 26 (see Table 1). Statistical analyses confirm OWAS's tendency to underestimate, as the Wilcoxon signed-rank test demonstrated significantly higher REBA scores for postural load ($p < 0.01$).

3.4.5. REBA vs PERA

Figure 4(b) illustrates the relationship between REBA and PERA. Among 1,111 postures, 379 matched levels (56 in level 1, 177 in level 2, 46 in level 3, and 100 in level 4), resulting in approximately 34.11% agreement. REBA overestimated 209 and underestimated 523 postures compared to PERA. Table 1 shows risk levels: 622 differed by one level, 94 by two, and 16 by three. Statistical tests confirm REBA's tendency to underestimate, with the Wilcoxon signed-rank test indicating significantly higher PERA scores ($p < 0.01$).

3.4.6. PERA vs OWAS

Figure 4(c) illustrates the OWAS and PERA cluster-level relationship across 1,111 postures: 334 share identical cluster levels (111 in level 1, 64 in level 2, 24 in level 3, and 135 in level 4). The remaining 777 postures showed divergent cluster levels, resulting in a 30.06% agreement between the two methods. Of these 777, OWAS overestimated 129 postures and underestimated 648 compared to

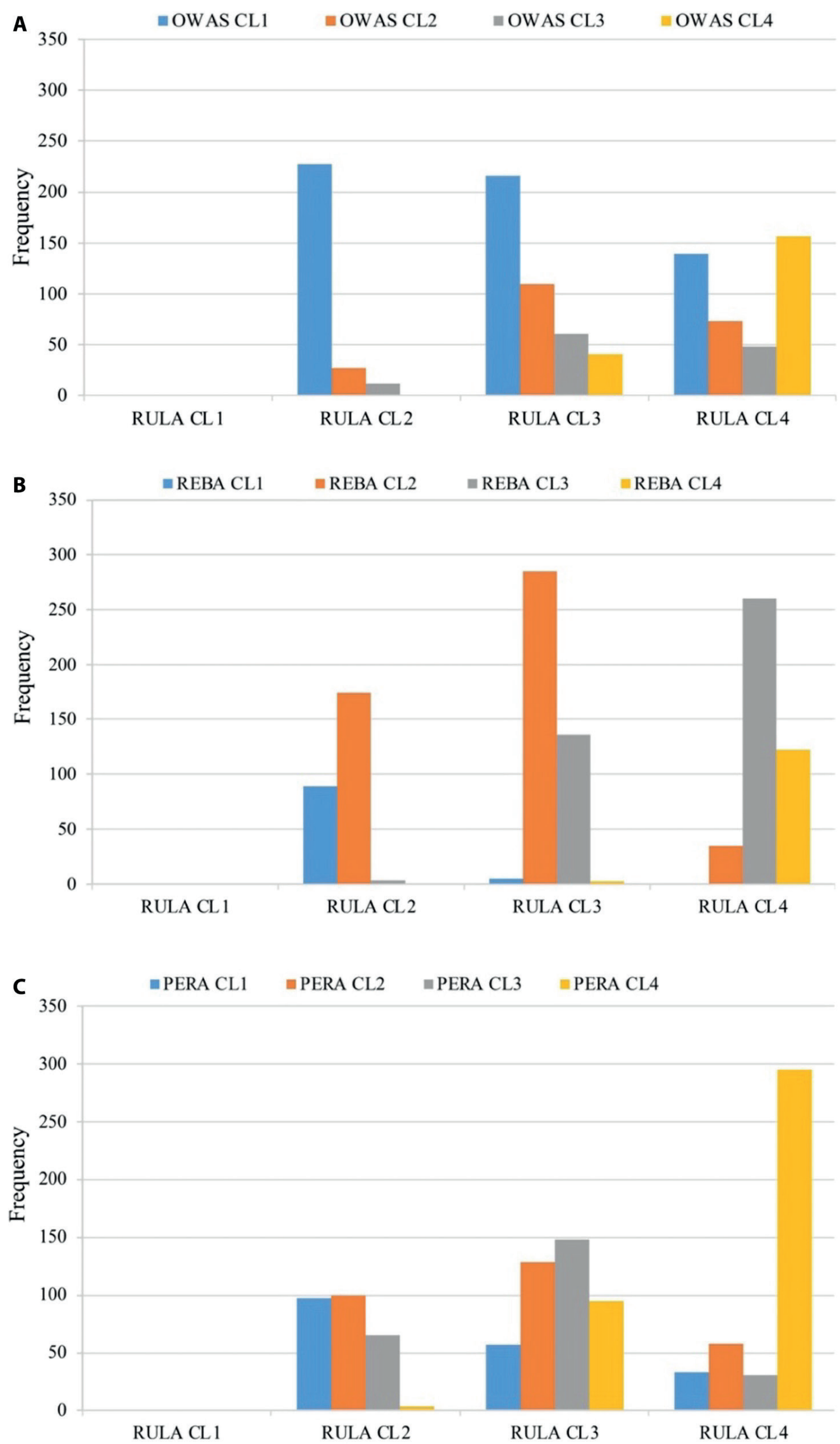

Figure 3. Frequency distribution of risk level (a) RULA vs OWAS (b) RULA vs REBA (c) RULA vs PERA

Table 1. Risk level differences and percentages (in brackets) between pairs of assessment methods.

Pair	0 level risk	1 level risk	2 level risk	3 level risk
RULA vs OWAS	245 (22.05)	438 (39.42)	289 (26.01)	139 (12.52)
RULA vs REBA	432 (38.88)	639 (57.52)	40 (3.6)	0 (0)
RULA vs PERA	543 (48.88)	416 (37.44)	119 (10.71)	33 (2.97)
REBA vs OWAS	355 (31.95)	582 (52.39)	148 (13.32)	26 (2.34)
PERA vs REBA	379 (34.11)	622 (55.99)	94 (8.46)	16 (1.44)
PERA vs OWAS	334 (30.06)	343 (30.88)	265 (23.85)	169 (15.21)

PERA. Table 1 presents the risk level differences: 343 postures had a one-level difference, 265 had a two-level difference, and 169 had a three-level difference. Statistical tests confirm that the OWAS method tends to underestimate; PERA scores for postural load are significantly higher than OWAS scores ($p < 0.01$), as per the Wilcoxon signed-rank test.

The results of the postural assessments revealed significant differences in the scores assigned by each method. The RULA method consistently indicated higher postural load scores than OWAS, REBA, and PERA. This can be attributed to its detailed focus on upper limb postures, which are heavily involved in rubber tapping [40]. In contrast, methods like OWAS and REBA take a more holistic approach by considering overall postural loads. OWAS effectively categorized overall postures during activities involving full-body movements. REBA included additional risk factors, such as trunk flexion and leg postures, providing a more balanced evaluation of tasks that involve bending and sustained positions.

PERA, originally developed for industrial environments, offered a unique perspective by evaluating cumulative ergonomic loads across the tapping work cycle. This approach highlighted the cyclical nature of rubber tapping tasks, particularly for repetitive actions like "Incision on the Channel". While PERA does not emphasize individual postures as heavily as other methods, its ability to assess cumulative fatigue and exertion provided valuable insights into the long-term ergonomic implications for rubber tappers.

These findings underscore the importance of aligning ergonomic assessment methods with the specific demands of the work being analyzed. Tasks involving significant upper-limb engagement may be best assessed using RULA, while OWAS and REBA are more appropriate for evaluating whole-body postural demands. Similarly, PERA's cumulative approach complements these methods by addressing repetitive strain and long-term workload in dynamic tasks.

3.5. Postural Criticalities and Method Application

In assessing ergonomic risks among rubber tappers, it is crucial to understand the specific postural criticalities that each method best captures and their respective scopes of application. Each method—OWAS, RULA, REBA, and PERA—has distinct strengths that make it particularly suitable for highlighting different aspects of postural risk in rubber tapping tasks.

OWAS effectively provides a broad overview of general postural risks associated with the back, arms, and legs. This method emphasizes static postural assessments without considering the duration or specific force exerted. OWAS is particularly useful for identifying high-risk postures that might occur sporadically but still pose significant ergonomic risks. Its application is well-suited for various segments of the workforce, providing a snapshot of postural strain across multiple body regions.

RULA is highly sensitive to upper limb activities, including the neck, trunk, and arms. This method is particularly effective at identifying risks associated with repetitive and intricate hand and arm movements, which are common in rubber tapping tasks. RULA's detailed focus on the upper limbs makes it suitable for tasks requiring fine motor skills and precision, such as making incisions on rubber trees. This method captures the nuances of upper limb postural strain that may be overlooked by more generalized assessments.

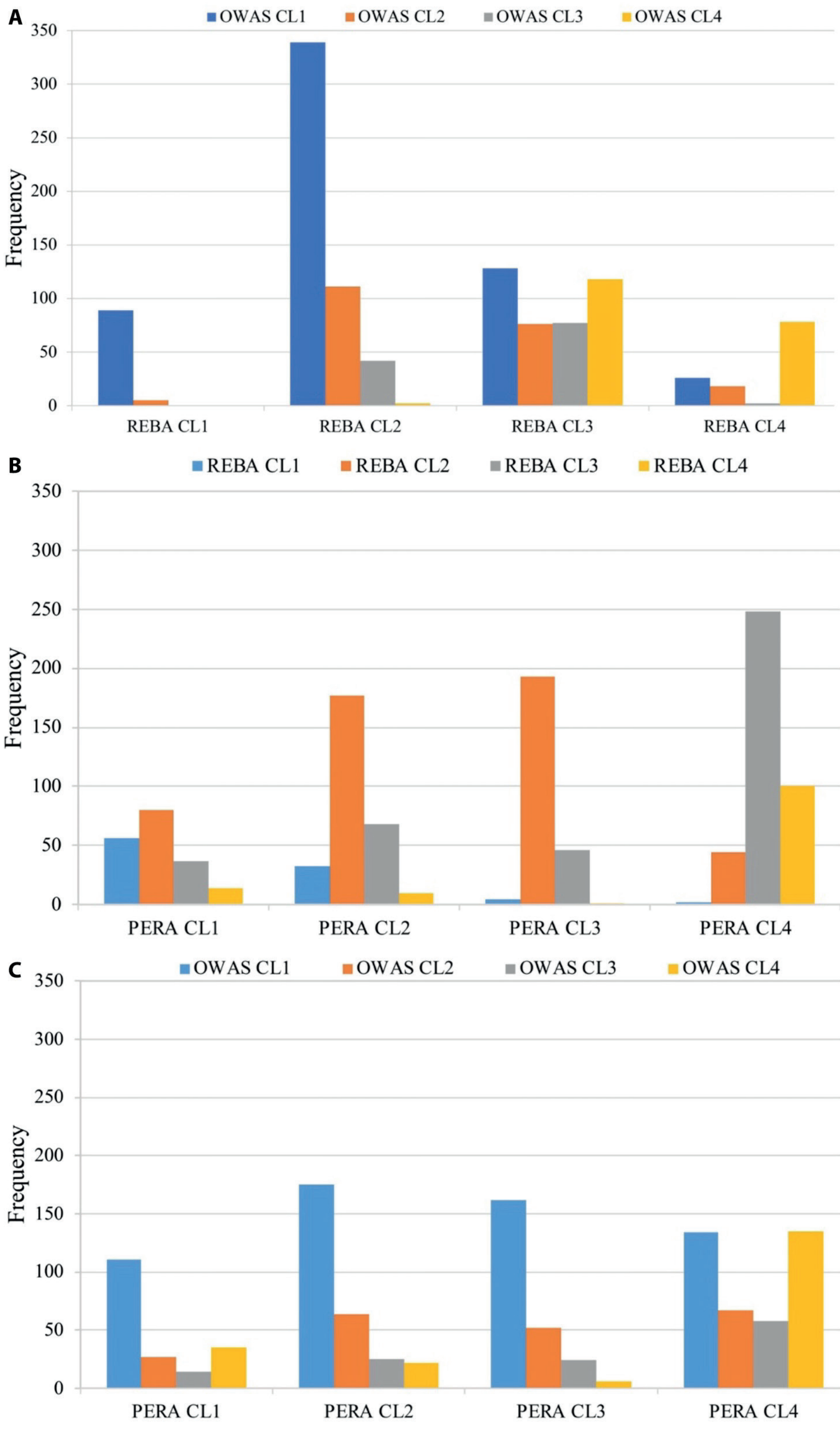

Figure 4. Frequency distribution of risk level: (a) REBA vs OWAS (b) PERA vs REBA (c) PERA vs OWAS.

REBA offers a thorough assessment of whole-body postures, taking into account factors such as postural angles, forceful exertions, and the nature of movements. This method captures the complete range of postures adopted during rubber tapping activities, making it ideal for tasks that require significant physical effort and varied body movements. REBA's capability to evaluate both upper and lower body postures renders it especially valuable for identifying ergonomic risks in activities that involve bending, twisting, and lifting.

PERA evaluates postural risks throughout the entire work cycle by considering posture, duration, and force. This method is particularly effective for assessing repetitive and cyclic tasks, providing a detailed analysis of high-risk activities over time. PERA's ability to account for the cumulative effects of duration and force makes it highly relevant to the continuous and repetitive nature of rubber tapping. This approach offers a comprehensive understanding of the long-term ergonomic risks associated with sustained and repetitive postural strain.

The application of these methods revealed significant variability in risk identification. RULA, focusing on upper limb activity, identified higher risk levels for postures involving precise and repetitive movements, such as those seen during the "incision" subtask. Conversely, OWAS and REBA provided broader risk assessments across the entire body, identifying trunk flexion and awkward leg postures as critical risk factors. PERA highlighted cumulative risks associated with repetitive tasks and prolonged durations, emphasizing the importance of evaluating work cycles holistically.

The results of this study align with those of Pramchoo et al. [42], particularly in acknowledging that awkward wrist postures significantly contribute to ergonomic risks in rubber tapping. However, this study builds on their conclusions by offering detailed cumulative load assessments using the PERA methodology. The correlation of REBA and OWAS scores with the identified risks in upper limb and back postures further emphasizes the necessity for task-specific ergonomic tools that incorporate total body and wrist-specific risk evaluations.

4. Conclusion

The implementation of OWAS, REBA, RULA, and PERA in ergonomic risk assessment for rubber tappers provided essential insights into workplace conditions and postural constraints. Most rubber tappers were middle-aged men with extensive expertise, and many viewed rubber tapping as a secondary occupation. The subtask 'Incision on the Channel' involved the most postures, many of which were inadequate due to their repetitive nature. The upper limbs and back experienced the greatest strain. Many postures were performed "below shoulder level" indicating that workers predominantly tap at this height.

The RULA method was deemed the most suitable for assessing upper limb postures in rubber tapping, highlighting the necessity of selecting ergonomic tools aligned with specific work activities. Each technique—OWAS, RULA, REBA, and PERA—has unique strengths: OWAS provides an overview, RULA focuses on upper limbs, REBA assesses the whole body, and PERA evaluates cyclic work with posture, duration, and force.

The key limitation is the sample size of 51 rubber tappers, which could affect the understanding of ergonomic risks across diverse demographics. Moreover, the assessment methods did not consider other factors, such as equipment design, environmental conditions, or psychosocial elements. Overall, the research calls for a comprehensive approach to assessing ergonomic risks in rubber tapping. It recommends multiple assessment methods with a preference for RULA due to its focus on upper limb engagement. Tailored ergonomic interventions should consider specific work tasks and tapping levels to enhance the well-being of rubber tappers, offering valuable guidance for policymakers and plantation owners aiming to improve working conditions in the industry.

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