**Journal of Information Systems Engineering and Management**
2025, 10(13s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

**Research Article**

# Ergonomic Risk Assessment and Work-Related Musculoskeletal Disorders in Seated and Standing CNC Operators

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**ARTICLE INFO**

Received: 28 Nov 2024
Revised: 10 Jan 2025
Accepted: 31 Jan 2025

**ABSTRACT**

Objective: This study is to assess the ergonomic challenges faced by CNC machine wheelchair-bound and standing posture operators, this study to identify the risk factors contributing to Work-Related Musculoskeletal Disorders (WMSDs). This research specifically determines which operators are more susceptible to WMSDs by evaluating the ergonomic compatibility of CNC machine designs for standing and wheelchair-bound operators.

Methods: Data were collected from 124 CNC machine operators, including 11 wheelchair users, through structured interviews, discomfort questionnaires, and direct observation of tasks. A discomfort mapping technique, based on Corlett & Bishop's method, was used to assess body pain and discomfort at different work intervals. Injury records were reviewed, and capture discomfort ratings from operators. Using quantitative evaluation tools, anthropometric data for standing and wheelchair-bound operators were analyzed to identify the critical ergonomic risk factors. Discomfort ratings were further analyzed using one-way ANOVA to determine the significance of various factors. The identified significant ergonomic risks were assessed using the Rapid Upper Limb Assessment (RULA) tool to evaluate physical workloads and awkward postures.

Results: The study found significant discomfort more in wheelchair-bound operators as compare to standing posture operators. The discomfort in wheelchair-bound operators due to awkward postures, repetitive tasks, and poor machine accessibility, particularly affecting the neck, shoulder, and lower back conversely standing operators reported significant discomfort, particularly in the abdomen, chest, and knees. A comparative analysis and quantitative analysis highlighted that the ergonomic design of CNC machines profiles revealed that only a few designs are ergonomically suitable for both seated and standing operators and often fails to accommodate mostly wheelchair users effectively, resulting in awkward postures and repetitive strain injuries.

Conclusion: The findings highlight the need for ergonomic interventions in CNC machine design to improve accessibility for wheelchair-bound more as compare to standing posture operators and reduce WMSD risks. Inclusive design modifications, such as adjusting machine height and improving monitoring window placement, can significantly enhance operator comfort and efficiency..

**Keywords:** Ergonomic Risk Factors, Work Related Musculoskeletal Disorder (WMSD), CNC Machines, ANOVA.

## INTRODUCTION

Working Operators in CNC operations with disabilities cause' accidents at the workplace and can repossess and continue evocative employment. Conventionally, persons with a disability had inadequate occupational opportunities but were constrained from working among persons without disabilities. (Marino et al., 2019) The Opportunity to regain work in regular tasks gives disabled persons an opportunity to reassess employment options that had previously been unavailable to them.(Kwon, 2020)

Through supported employment, individuals with severe disabilities can work in real businesses in the community with persons without disabilities, earn competitive wages and receive individualized, ongoing support services to help them successfully
maintain their employment.(García-Sabater et al., 2020) As per Census 2011, in India, out of the 121 Cr population, about 2.68 Cr persons are 'disabled' which is 2.21% of the total population. The Census 2011 revealed that, In India, 20% of disabled persons have a disability in movement (Wheel Chair Users) (Persons with Disabilities in India - A Statistical Profile, 2021). Occupational safety is a fundamental physical and psychosomatic need of the working person. Industrial accidents injure 7,20,000 working persons around the globe.(Majumder, 2019)(Salam et al., 2021) From 2008-2015, 374 million injuries in working personal work-related accidents per year.(Hussen et al., 2020) Work-Related Musculoskeletal Disorder (WMSD) is the foremost problem for industrial workers. The upper limb (neck and shoulder region) is the main muscle that is more prone to WMSDs for operators in overhead work posture workers. The wheelchair user operators in seating posture need to perform overhead work in CNC machines.(Özcan, 2021)(Segar & Rahman, 2019) The operators during the performance of regular working and manual material handling operations need to go through awkward positions. The purpose of this study is to assess the different awkward postures of movement disability wheelchair user and standing operators working in a CNC machine and to identify ergonomic risk factors for WMSD(Mistarihi, 2020)(Muthukumar et al., 2012). Another important aspect is that the successful identification of ergonomic risk factors for Work-Related Musculoskeletal Disorder (WMSD) helps with the help of a structured interview questionnaire. (Lop et al., 2019)After finding the most influencing ergonomic risk factor ergonomic assessment was carried out with RULA Ergonomic Assessment tool. The aim of this study to determines which operators are more susceptible to WMSDs by evaluating the ergonomic compatibility of CNC machine designs for standing and wheelchair-bound operators The Assessment result integrates to build the most favorable environment for motivating a successful Return to Work in disabled workers.(Erliana et al., 2019)(Özcan, 2021)

## 2. METHODS

This study was conducted in the CNC machining industry in which around 124 male CNC operators, ages 25 to 57 Years out of which 13 operators suffered from occupational accidents during performance of routine operation. All operators were considered for discomfort study to identify the ergonomic risk factors that cause work-related musculoskeletal disorders. The operators were implicated in the study well-versed and obtained consent from them. (Chatterjee & Sahu, 2018)

### 2.1 Study of CNC machines

Various design profiles of CNC machines have been studied and according to customer needs varying customer necessities cause vast revisions usual common design of CNC machines.(Muthukumar et al., 2012) Every manufacturer wants to effectively utilize proficient tools for achieving productivity. Computer Numerically Controlled (CNC) machines are extensively utilised in modern manufacturing functions, still, there is a shortage of skilled manpower to operate CNC machines (Job opportunities related to CNC).(Zhao, 2021)

Earlier studies have shown that accidents in the industry cause disabilities in operators having higher technical education & training. Disabled persons with good vocational training & hands-on experience in CNC machines can utilize machines more effectively after repossessing the job(Muthukumar et al., 2012)(Marino et al., 2019). In the manufacturing industry, various design profiles of CNC machines are not handy for disabled operators using wheelchairs. Hence, for the CNC machine manufacturing industry, it is not profitable to produce CNC machines according to various physical constraints of CNC operators.(Wu et al., 2011)(Liu et al., 2019) Providentially the modernization of technology is considered the most difficult part of the job to make the CNC machine compatible with both normal and disabled persons. The general type of machine profile design of CNC machines, includes the tool holder, the guard and an observation window, affect monitoring work, tool loading unloading, job loading unloading and operators(Guha & Anand, 1980)(Liu et al., 2019). This study's prime focus is on identifying ergonomic factors affecting the operations of wheelchair users selecting and improving CNC machine design profiles to enhance usability to all based on the machine profile proportional graphic analysis.(Soewardi & Afgani, 2019)(Wu et al., 2011)

The ability of CNC operators to monitor and perform different operations on CNC machines is affected due to different profiles of the CNC affect operators' ability to monitor the working tool process in two situations – standing up or sitting in a wheelchair.(Liu et al., 2019)(Lu, 2013)(Wu et al., 2011) These results affect the performance of CNC operators. In the CNC machining industry, CNC machine size varies abundantly. This paper emphasises the average size of CNC lathe machines. Systematic or average parameters have been considered. (Muthukumar et al., 2012) In this study random sample of the height of 22 CNC lathe machines was taken. It is observed that the average height of CNC lathe machines is 72” with a standard deviation is about σ=7.5.

In Indian CNC operators, the Ideal height for sitting variable work planes is 20” to 30”; the ideal height for standing variable work surfaces is 32” to 40”; The ideal fixed height for sitting and standing work surfaces is 32”, and the tool holder height is 32”. The distance of the tool from the operator is identified from random sampling of 8 out of 22 CNC Machines range of 12” to 15”, with hence average being 14”. The average height of the CNC machine is 72”, and the ideal height of the monitoring window is 24”. Monitoring window shape as per the shape of the guard, it is possible that the window can be at any location; hence it is expected that it is located at the intermediate of that CNC machine. The average CNC machine dimension is shown in Fig 2.1.

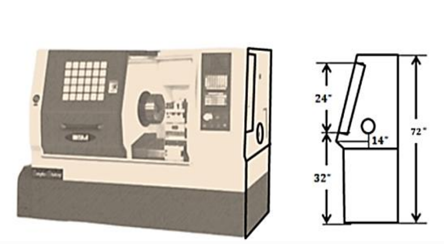


**Fig 2.1** The average CNC machine dimension

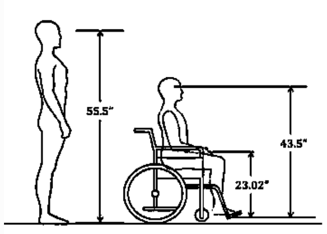


**Fig 2.2** Anthropometric measurements Indian males in standing and sitting

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Indian males anthropometric measurements for the Stature (average body height): Eye height (Standing): 55.5” Indian males wheelchair user anthropometric measurements for the (average sitting height): Eye height (Sitting): 43.5” Height of Knee: 23.02” as shown in Fig 2.2.(Chandna et al., 2010)(Yadav et al., n.d)(Muthiah et al., 2020)

The operators have to keep close to the CNC lathe, so they can work with it and monitor the process. In the standing situation, the distance between eyes and tool would be better within 32”-36”, it’s the range between safety and monitor clearly. In the wheelchair situation, the operator’s foot pad reaches the base of the CNC lathe. (Liu et al., 2019)(Hafiz et al., 2013)(Guha & Anand, 1980) If both of them can monitor the tool working clearly, this category of CNC lathe has a high level of universal usability.

“The operator monitors the machine tool working clearly” means: that when monitoring the tool working process, the operator’s line of sight can go through the range of the monitor window, where extending from the centre point of the window, the range is two-thirds of the distance between the centre point of the window and the top (or bottom) of the window.(Wang et al., 2010)

If the operator’s line of sight goes out of the monitor window, it means the operator can’t monitor the tool. Otherwise, it means it is difficult for operators to CNC machines. The results of the analysis as shown in the Table 2.1, that the comparison of wheelchair operators and operators without disability capability to monitor the CNC lathe machine operation.(Guha & Anand, 1980)

It is observed that wheelchair operators and standing operators can monitor effortlessly the CNC lathe Machine operation in the case of six sample profiles of CNC lathe machines like 2, 4, 6, 9, 12 and 13. Operators need to essentially open the monitoring window guard for tool and workpiece changing & adjustment.

The CNC lathe operators seating in wheelchairs can get closer to the machine like to reach the guard, tools, and workpieces due to the CNC lathe machine profile's low height. It is observed that based on profile to accommodate wheelchair users 4, 6, 9 and 12 are the most suitable CNC lathe machines.(Marino et al., 2019)(Lu, 2013)

**Table2.1:** Comparative Analysis of capability to monitor the CNC lathe machine operation

| CNC lathe Sample | Operators with Wheelchair (a) | Operators without Wheelchair (b) |
|---|---|---|
| 1 | ML | MWE |
| 2 | ME | ME |
| 3 | MWE | ME |
| 4 | ME | ME |
| 5 | ML | MWE |
| 6 | ME | ME |
| 7 | MWE | ME |
| 8 | MWE | ME |
| 9 | ME | ME |
| 10 | MWE | ME |
| 11 | ML | MWE |
| 12 | ME | ME |
| 13 | ME | ME |
| 14 | ML | MWE |
| 15 | MWE | ME |
| 16 | MWE | ME |
| 17 | MWE | ME |
| 18 | MWE | ME |
| 19 | ML | MWE |
| 20 | ML | MWE |
| 21 | MWE | ME |
| 22 | ML | MWE |

ME = Monitor Effortlessly, MWE = Monitor with Effort and ML = Monitor less

**2.2 Assessment of Discomfort for CNC Operators in Seating and Standing Posture**

The operator in seating posture body part experiences pain and discomfort during the performance of work in awkward posture due to Stretching, Overhead work, Awkward Posture, Manual material handling, Repetitiveness of work, Long duration of work, Forceful Exertions, Repetition of Work, Awkward Postures, Prolonged Static Positions, Foot & Knee causes work-related musculoskeletal disorders. The procedure of discomfort assessment by identifying risk factors stress in the various body parts by determining concentrations and frequencies of pains taking place to the body parts during execution of various tasks. In sitting posture CNC lathe operators most critical problem is Postural discomfort.(Muthukumar et al., 2012)(Hafiz et al., 2013)

The most frequently and extensively known technique of collecting body discomfort data is a questionnaire with structured interviews. The technique of discomfort assessment with a questionnaire is economical, acceptable and suitable for fieldwork.(Corlett & Bishop, 1976) Corlett & Bishop's method of body mapping is applied for collecting data for body discomfort. Corlett & Bishop's method is a very popular technique by numerous researchers for identifying the positions of pain and their concentrations in various erratic tasks. The discomfort assessment study was carried out to identify the potential causes of the discomfort and frequencies of development of discomfort over the period, to provide critical interferences indicators. (Corlett & Bishop, 1976)(Muthukumar et al., 2012)(Krishnan et al., 2021)

**2.2 Questionnaire survey**

Many of the researchers used Corlett and Bishop's body part discomfort mapping method to find out the positions of pain with intensities in changing tasks. The purpose of a discomfort study was to assess and identify the ergonomic risk factors that cause discomfort at variable intervals of time, to provide indicators for intervention(Muthukumar et al., 2012)(Corlett & Bishop, 1976).

The questionnaire of Corlett and Bishop's for body part discomfort mapping was asked to be filled by CNC operators in standing and seating posture. The questionnaire with different discomfort levels was distributed to CNC operators and asked to state the discomfort levels like not uncomfortable, slightly uncomfortable, moderately uncomfortable, severely uncomfortable, and very uncomfortable. (Khan, 2014)(Kee, 2002)

The discomfort level score was assigned the levels of 0, 1, 2, 3 and 4 respectively, the body parts of CNC Operators in standing and sitting posture during the different intervals of time of shifts like at the beginning of a shift, at the start and end of lunch break, after the shift. After the responses were recorded the discomfort level scores were tabulated to determine operators everybody part's discomfort level. (Kee, 2002)

**2.3 Discomfort mapping**

Discomfort assessment aims to identify ergonomic risk factors in different body parts under stress by repeated action during the performance of tasks, prolonged stationary or awkward postures, and prolonged working exertion due to awkward movement of body parts. (Cameron, 1996)

In CNC machines operator's most critical problem is related to Postural discomfort. The questionnaire is the most frequently and extensively used method for collecting information on body discomfort. Corlett and Bishop's method is economical and suitable for body mapping and collecting information on body discomfort. (Susihono et al., 2020)

In this study, a body map with a five-point Scale was used. The five-point scale, fixed with the terms "Not uncomfortable, Slightly uncomfortable, Moderately uncomfortable, Severe Comfortable, Very Comfortable", in this questionnaire every operator was asked the level of discomfort. The operators were asked to specify the body part experienced most uncomfortable during the performance of work. (Hafiz et al., 2013)(Yang et al., 2009)

The questionnaire circulates at consistent intervals once at the beginning of work, at the beginning of the first break, at the beginning of lunch, at after lunch, and at the end of work. This procedure was conducted during the whole day to study the development of discomfort during the performance of work. (Muthukumar et al., 2012)

**2.4 Sample**

The 124 CNC Machine operators from three CNC Machining industries were participated in the study. The study was conducted by separating operators into 3 age groups like less than 35 age, 35-49 and 50-59). The mean age is 47 years (standard deviation [SD] = 12) and the mean height is 163.1 cm (SD = 5.96) as show in Table 2.2

**Table2.2:** Demographic and anthropometric data

Main characteristics of the respondents (n = 124).

| | **Standing CNC Operators** | **Seating CNC Operators** | **Standing & Seating CNC Operators** |
|---|---|---|---|
| **Respondent Number** | 113 | 11 | 124 |
| **Age (Years)** | 60.0±9.0 (≤30)<br>14.0±2.0 (35-49)<br>10.0±4.0 (50-59) | 2.0±1.0 (≤30)<br>5.0±1.0 (35-49)<br>1.0±1.0 (50-59) | 62.0±10.0 (≤30)<br>19.0±3.0 (35-49)<br>11.0±5.0 (50-59) |
| **Weight (Kg)** | 50-75 | 40-85 | 50-85 |
| **Height (cm)** | 158.5-182.88 | 115.82-121.92 | 115.82-182.88 |
| **Body Mass Index (BMI) (Kg/m2)** | 19.9-22.4 | 29.8-57.2 | 25.4-37.3 |
| **Experience (Years)** | 0.5-32 | 15-37 | 0.5-35 |

**2.4 Work**

The process of CNC machine with standing posture operators for performing the machining operation by removing the excess material and giving the desired shape and size. In this machining process, various tasks need to be performed like lifting the workpiece, loading the workpiece in the work holding device, loading the tool in the tool holding device CNC machine operator controller key panel operations, Unloading the workpiece after the machining operation is completed and observation machine operation with quality assurance of the necessary technical specifications, like all dimensions and geometries, of desired design of the product. (Denkena et al., 2022)

**2.5 Data collection**

This study follows the ethics of data collection. The CNC operator's participation in this study was voluntary. The purpose of the study was well informed to all participants. The study was conducted in the industry by giving brief information & obtaining prior permission from authorities. The questionnaires were distributed and asked to be completed during structured interviews by operators. The structured interview & questionnaire were conducted during different shifts in the presence of the researcher. The study was completed after the participation of 98% of operators. The operators answered the structured interview with the questionnaires and returned them backed by signed consent. (Delvolvé & Quéinnec, 1983)

**2.6. Data analysis**

In this study various work postures in the number of cases recorded of CNC seating & standing Operators Fig. 2.3 & Fig 2.4 In the CNC Machine working cycle like load lifting, tool fixing, control panel operation, work observation, job loading and unloading.(Muthukumar et al., 2012)(Hafiz et al., 2013) The structured interview was conducted with a questionnaire over a year for standing & seating operators, those who conveyed the condition at that moment were divided by the number of operators questioned(Ismaila et al., 2020).

The yearly occurrences of Work-Related Musculoskeletal Disorder (WMSD) claims were considered by dividing the number of claims per year except for re-claims by the number of operators per year. The data analysis includes descriptive statistics and correlation of means using the SPSS (Statistical Package for Social Sciences). (Dev et al., 2018)The respondent's characteristics Age, Weight, Height, Body Mass Index and the discomfort ratings of CNC Operators in standing & seating posture were compared using independent samples t-test. The discomfort rating of the body parts of CNC operators with standing & Seating posture The body parts discomfort ratings, and the five VAS, were compared using one-way ANOVA with Fisher's least-significant difference post hoc test. Differences were considered significant when $p<0.05$.(Kee, 2002)(Hafiz et al., 2013)

Demographic and anthropometric data were measured using typical tools like measuring tape, a Goneometer and an anthropometer. The eye & shoulder height was measured in standing & seating posture. They were asked to keep the chair to the most comfortable posture can achieve the most comfortable position that respondent can feel. The respondents were asked to select five preferences for rating their physical comfort & discomfort for performing the tasks.(Kee, 2002)

The preferences were 0=Not Uncomfortable 1=Slightly Uncomfortable, 2=Moderate Uncomfortable 3=Severe Uncomfortable 4=Very uncomfortable (Yang et al., 2009) The RULA postural assessment of seating and standing posture operators. The awkward postures of seating posture operators are observed as shown in Fig 2.3. Bending trunk & Back for lifting workpieces from the ground, 2. Leaning the Upper arm and Twisting the Trunk for Opening the Safety door to open it, 3. Leaning upper arm, Twisting and Bending Trunk for loading job, 4. Leaning Upper Arm and side Bending trunk for tool loading, 5. Leaning Upper arm and Twisting Trunk for Closing the Safety door, 6. Shoulder Raising, Upper Arm Abduction and Neck Bending in Extension to operate the key panel, 7. Leaning Upper Arm, Shoulder Raising, Upper Arm Abduction and Neck Bending in Extension reaching to Control Panel keypad 8. Leaning upper arm, Twisting and Bending Trunk for adjusting tool, 9. Observation by seating in Wheelchair Courses Abduction of Vision. The RULA assessment score is 6 for the first seating posture CNC operator trunk position at $60^{o}$ in the forward direction with neck bending at 200 upper arm, lower arm needs to be stretched at $90^{o}$ and wrist movement bend from the middle at $15^{o}$ to hold the work piece interface with CNC Machine. The second seating posture CNC operator RULA scores is 7 for twisting the trunk to open the safety door of the CNC machine $20^{o}$. Neck bend in extension, upper arm and lower arm abducted above the shoulder level at more than $90^{o}$, wrist twist with bending at $15^{o}$. The third seating posture CNC operator RULA score is 7 bending trunk at $60^{o}$, neck twisted with bending at $20^{o}$, Upper Arm and lower arm abducted at more than $90^{o}$, Wrist get twisted and bend from middle. The fourth seating posture CNC operator RULA score is 7 trunk bending at $60^{o}$ for job adjustment, neck in extension, upper arm and lower arm abduction at more than $90^{o}$ and wrist get twisted for job locating with bed from middle.

The fifth seating posture CNC operator RULA score is 7 twisting trunk for closing the safety door at $60^{o}$, Neck in extension, upper arm lower arm abduction at more than $90^{o}$, and Wrist bend from the middle. The sixth seating posture CNC operator RULA score is 7 shoulders raising with upper arm and lower arm abduction at more than 90°, trunk getting twisted, neck in extension. The seventh seating posture CNC operator RULA score is 7 Shoulder raising with Upper arm & Lower arm abduction at more than 90°, truck twist and neck bending at an extension. The eight seating posture CNC operator RULA score is 7 trunk twists, bending at 60° and abduction of upper and lower arm at more than 90°. The ninth seating posture CNC operator vision abduction causes.

The assessment and evaluation of work postures for CNC operators in a seated posture, focusing on musculoskeletal disorder prevalence, revealed key findings based on RULA scores. Out of 13 CNC operators evaluated, the majority fell into higher discomfort categories. Specifically, 38.46% of operators were found to be in the "Very Uncomfortable" category with a RULA final score of 7, indicating the need for immediate investigation and change. Additionally, 23.08% of operators had a RULA score of 5-6, categorizing them as "Severely Uncomfortable." Meanwhile, 15.38% of operators were considered "Moderately Uncomfortable" with a score of 3-4, and another 15.38% reported being "Slightly Uncomfortable" with scores of 1-2. Only 7.69% of operators were deemed "Not Uncomfortable" with a score of 0. This distribution highlights the need for ergonomic interventions to address discomfort and reduce the risk of musculoskeletal disorders.

The Table 2.16 shows the one-Way ANOVA test results reveal significant discomfort in various body parts of CNC operators, which can contribute to work-related musculoskeletal disorders (WRMDs). The shoulder (F=116.96, P<0.00) exhibited the highest level of discomfort, indicating a strong relationship between work tasks and core muscle strain, likely due to poor posture or repetitive motions. Similarly, the Upper Arm (F=42.761, P<0.00) and Lower Arm (F=6.136, P=0.003) also showed significant discomfort, suggesting that upper body strain from overhead work during CNC operations is a key issue. The Neck (F=4.584, P=0.012) discomfort points to the impact of repetitive fine motor tasks on the operators. Discomfort in the Wrist (Placket side) (F=4.701, P=0.011), Hand (Thumb side) and Hip (F=4.245, P=0.017) further supports the notion that prolonged static positions and repetitive overhead movements contribute to upper body strain, consistent with ergonomic studies showing the prevalence of neck, shoulder and arm issues in seating posture CNC operators. The eyes (F=4.584, P=0.012) also demonstrated significant discomfort, likely related to continuous screen monitoring at sight abduction and prolonged improper seating postures. Conversely, the knees, lower legs, upper legs, ankles, and feet showed no statistically significant discomfort (P>0.05), indicating that lower body strain is less of a concern compared to upper body and core regions.

However, these areas should still be considered in comprehensive ergonomic assessments to ensure overall operators health. This analysis underscores the importance of addressing upper body strain and repetitive overhead hand motions through ergonomic interventions to reduce the risk of WRMDs among CNC operators. Table 2.17 presents the distribution of discomfort levels across different body parts average discomfort from beginning of shift to end of CNC operators, highlighting the areas most affected by work-related musculoskeletal strain. The neck, hand (Thumb side), wrist (placket side), hip, upper arm, and shoulder report the highest levels of discomfort, with 90.1% to 92.0% of operators experiencing extreme discomfort (Level 7). This indicates that these body parts are under significant strain, likely due to repetitive tasks, poor posture, overhead work and prolonged static positions during CNC machine operation. The abdomen, chest and lower body parts such as the foot, ankle, keen, upper leg and lower leg predominantly show slight discomfort, with most operators experiencing discomfort at Level 1 (around 0.8% to 79.8%). These slight discomfort levels suggest some strain but not to the extreme levels as seen in the upper body and neck regions. For the abdomen, chest and lower body parts such as the foot, ankle, keen, upper leg and lower, less discomfort is observed, with operators experiencing slight discomfort levels (Level 2). In particular, hip observed moderate discomfort levels (Level 3) is 7.3%. Experience eye strain at Level 7, reflecting the demands placed on visual during machine monitoring and control. In summary, the upper body (especially the neck, hand (Thumb side), wrist (placket side), hip, upper arm, and shoulder), along with the hips, experiences the most extreme discomfort, indicating a critical need for ergonomic interventions in these areas to reduce the risk of work-related musculoskeletal disorders. The moderate discomfort in the lower body, although less severe, also calls for attention to improve overall worker comfort and safety.

**Fig 2.3:** Ergonomic Risk Postures for Seated CNC Operators: 1. Lifting Work piece from Ground, 2. Opening Safety Door, 3. Loading Work piece, 4. Loading Tool, 5. Closing Safety Door, 6. Operating Key Panel, 7. Operating Control Panel, 8. Adjusting Tool, 9. Monitoring Control Panel

**Table 2.15:** Frequency of Risk Assessment score in this study

| Results of risk assessment by RULA (n=13) | | | | |
|---|---|---|---|---|
| **Risk level** | **Risk rate** | **RULA final score** | **Frequency** | **Percent** |
| 0 | Not uncomfortable | 0 | 1 | 7.69 |
| 1 | Slightly uncomfortable | 1-2 | 2 | 15.38 |
| 2 | Moderate uncomfortable | 3-4 | 2 | 15.38 |
| 3 | Severe uncomfortable | 5-6 | 3 | 23.08 |
| 4 | Very uncomfortable | 7 | 5 | 38.46 |

**Table 2.16:** One way ANOVA test discomfort level of body part for seating posture operator

| One Way ANOVA Test P<0.05 (n=13) | | | |
|---|---|---|---|
| **Body Part** | **F-value** | **P-value** | **Significant (Yes/No)** |
| Abdomen | 0.885 | 0.416 | No |
| Ankle | 0.721 | 0.192 | No |
| Chest | 0.571 | 0.567 | No |
| Eyes | 4.584 | 0.012 | Yes |
| Foot | 0.601 | 0.164 | No |
| Hand (Thumb side) | 4.245 | 0.017 | Yes |
| Hip | 4.245 | 0.017 | Yes |
| Knee | 2.095 | 0.127 | No |
| Lower Arm | 6.136 | 0.003 | Yes |
| Lower Leg | 1.753 | 0.178 | No |
| Neck | 4.584 | 0.012 | Yes |
| Shoulder | 116.96 | < 0.00 | Yes |
| Upper Arm | 42.761 | < 0.00 | Yes |
| Upper Leg | 0.783 | 0.46 | No |
| Wrist (Placket side) | 4.701 | 0.011 | Yes |

**Table 2.17:** Discomfort Distribution and Severity by Body Part in seating posture operator

| Body Part | Distribution Discomfort from beginning of shift to end in Level 1-7 (%) |
|---|---|
| Abdomen | 0 (3.2%), 1 (79.0%), 2 (17.7%) |
| Chest | 0 (3.2%), 1 (0.8%), 2 (80.6%), 3 (15.3%) |
| Neck | 6 (8.9%), 7 (91.1%) |
| Eyes | 0 (2.0%), 6 (7.9%), 7 (90.1%) |
| Foot | 0 (3.2%), 1 (78.2%), 2 (18.6%) |
| Ankle | 0 (1.6%), 1 (79.8%), 2 (18.6%) |
| Lower Leg | 0 (3.2%), 1 (78.3%), 2 (18.5%) |
| Knee | 0 (4.8%), 1 (3.2%), 2 (91.2%), 3 (0.8%) |
| Upper Leg | 0 (4.0%), 1 (76.6%), 2 (19.4%) |
| Hip | 0 (2.4%), 3 (7.3%), 4 (90.3%), |
| Hand (Thumb side) | 6 (8.0%), 7 (92.0%) |
| Wrist (Placket) | 6 (8.9%), 7 (91.1%) |
| Lower Arm | 4 (9.7%), 5 (90.3%) |
| Upper Arm | 6 (9.7%), 7 (90.3%) |
| Shoulder | 6 (8.1%), 7 (91.9%) |

**Fig2.4:** Ergonomic Risk Postures for Seated CNC Operators: 1. Lifting Work piece from Ground, 2. Loading Work piece, 3. Loading Tool, 4. Operating Safety Door, 5. Operating Key Panel & Control Panel, 6. Monitoring Control Panel

**Table 2.18:** Frequency of Risk Assessment score in this study

| Results of risk assessment by RULA (n=111) | | | | |
|---|---|---|---|---|
| **Risk level** | **Risk rate** | **RULA final score** | **Frequency** | **Percent** |
| 0 | Not uncomfortable | 0 | 43 | 38.76 |
| 1 | Slightly uncomfortable | 1-2 | 26 | 23.42 |
| 2 | Moderate uncomfortable | 3-4 | 21 | 18.91 |
| 3 | Severe uncomfortable | 5-6 | 13 | 11.71 |
| 4 | Very uncomfortable | 7 | 8 | 7.2 |

**Table 2.19:** One way ANOVA test discomfort level of body part for standing posture operator

| One Way ANOVA Test P<0.05 (n=111) | | | |
|---|---|---|---|
| **Body Part** | **F-statistic** | **P-value** | **Significant (Yes/No)** |
| Abdomen | 0.443 | 0.643 | No |
| Ankle | 4.747 | 0.019 | Yes |
| Chest | 0.443 | 0.643 | No |
| Eyes | 4.459 | 0.014 | Yes |
| Foot | 4.425 | 0.014 | Yes |
| Hand (Thumb side) | 1.747 | 0.179 | No |
| Hip | 4.459 | 0.014 | Yes |
| Knee | 13.344 | <0.00 | Yes |
| Lower Arm | 0.441 | 0.645 | No |
| Lower Leg | 12.543 | <0.00 | Yes |
| Neck | 3.033 | 0.022 | Yes |

| | | | |
|---|---|---|---|
| Shoulder | 22.416 | <0.00 | Yes |
| Upper Arm | 0.544 | 0.582 | No |
| Upper Leg | 5.287 | 0.011 | Yes |
| Wrist (Placket side) | 1.747 | 0.179 | No |

**Table 2.20:** Discomfort Distribution and Severity by Body Part in standing posture operator

| Body Part | Distribution Discomfort from beginning of shift to end in Level 1-7 (%) |
|---|---|
| Abdomen | 0 (3.5%), 1 (62.8%), 2 (33.7%) |
| Chest | 0 (2.7%), 1 (7.0%), 2 (73.5%), 3 (16.8%) |
| Neck | 6 (7.1%), 7 (92.9%) |
| Eyes | 0 (3.5%), 7 (96.5%) |
| Foot | 0 (1.8%), 6 (77.9%), 7 (20.3%) |
| Ankle | 1 (1.8%), 6 (77.9%), 7 (20.3%) |
| Lower Leg | 0 (2.7%), 6 (77.0%), 7 (20.3%) |
| Knee | 6 (10.0%), 7 (90.0%) |
| Upper Leg | 0 (3.5%), 6 (79.7%), 7 (16.8%) |
| Hip | 0 (1.8%), 6 (91.2%), 7 (7.0%) |
| Hand (Thumb side) | 0 (2.7%), 1 (77.0%), 2 (20.3%) |
| Wrist (Placket side) | 0 (2.7%), 3 (71.7%), 4 (25.6%) |
| Lower Arm | 0 (6.2%), 1 (59.3%), 2 (28.3%), 3 (6.2%) |
| Upper Arm | 0 (2.7%), 1 (75.2%), 2 (22.1%) |
| Shoulder | 0 (1.8%), 6 (78.8%), 7 (19.4%) |

The data presented in the table provides an analysis of discomfort levels among operators based on the RULA (Rapid Upper Limb Assessment) final scores. A significant proportion of the operators, 38.76%, reported no discomfort (Risk rate: 0), indicating a relatively comfortable work environment for these individuals. However, 23.42% of the operators experienced slight discomfort (Risk rate: 1-2), suggesting that nearly one-third of the workforce encounters some level of strain during their tasks.
Moderate discomfort (Risk rate: 3-4) was reported by 18.91% of the operators, reflecting an increased ergonomic risk and the potential for long-term musculoskeletal issues if not addressed. More concerning, 11.71% of the operators reported severe discomfort (Risk rate: 5-6), which signifies a higher risk of musculoskeletal disorders and necessitates ergonomic intervention. Finally, 7.20% of the operators reported feeling very uncomfortable (Risk rate: 7), indicating an urgent need for corrective measures to improve workstation ergonomics and reduce strain on the body.
These findings emphasize the need for targeted ergonomic improvements, especially for operators experiencing moderate to very high discomfort, to prevent long-term health issues and improve overall workplace well-being.

The one-way ANOVA test results for standing CNC operators indicate significant discomfort in several key body parts. Most notably, the Shoulder (F = 22.416, P < 0.00), Lower Leg (F = 12.543, P < 0.00), and Knee (F = 13.344, P < 0.00) show strong statistical significance, highlighting areas of high physical strain. These findings suggest that these body parts are particularly prone to discomfort during CNC operation, possibly due to repetitive movements or prolonged standing postures.

Other significant areas of discomfort include the Upper Leg (F = 5.287, P = 0.011) Foot (F = 4.425, P = 0.014), eyes (F = 4.459, P = 0.014), hip (F = 4.459, P = 0.014), Ankle (F = 4.747, P = 0.019) and Neck (F = 3.033, P = 0.022). These results indicate potential ergonomic challenges, particularly in the lower extremities, likely linked to awkward, static & prolong postures during operation.

However, several body parts, including the Abdomen, Chest, Hand (Thumb side), Lower Arm, Upper Arm and Wrist (Placket side), did not show significant discomfort levels (P > 0.05). This suggests that these areas may experience less strain or discomfort, possibly due to better ergonomic positioning or less direct involvement in repetitive or stressful activities. Overall, the significant results in critical body parts like the Shoulder, Lower Leg, Knee, Upper Leg, Foot, eyes, neck, hip and ankle emphasize the need for ergonomic interventions, such as posture correction, work breaks, and workstation adjustments, to reduce the risk of musculoskeletal disorders for standing CNC operators. The analysis of discomfort distribution across various body parts from beginning of shift to end for CNC machine operators reveals several key insights. The majority of operators report moderate discomfort in the abdomen, with 62.8% falling under discomfort level 1, while 33.7% experience discomfort at level 2, suggesting this region is moderately strained during work. In contrast, discomfort in the chest shows also moderate levels, with 73.5% reporting

**Table 2.21:** Discomfort Distribution and Severity by Body Part at Different Stages of the Shift in Seated CNC Operators (Levels 1-7)

| Body Part | Beginning of Shift (%) | First Break (%) | Lunch Break (%) | After Lunch (%) | End of Shift (%) |
|---|---|---|---|---|---|
| **Abdomen** | 0 (1), 1 (50), 2 (49) | 0 (2), 1 (55), 2 (43) | 0 (3), 1 (60), 2 (37) | 0 (4), 1 (65), 2 (31) | 0 (5), 1 (70), 2 (25) |
| **Chest** | 0 (1), 1 (3), 2 (60), 3 (36) | 0 (1), 1 (5), 2 (62), 3 (32) | 0 (1), 1 (6), 2 (65), 3 (28) | 0 (2), 1 (8), 2 (72), 3 (18) | 0 (3), 1 (10), 2 (70), 3 (17) |
| **Neck** | 6 (20), 7 (80) | 6 (18), 7 (82) | 6 (15), 7 (85) | 6 (12), 7 (88) | 6 (10), 7 (90) |
| **Eyes** | 0 (1), 6 (5), 7 (94) | 0 (1), 6 (6), 7 (93) | 0 (1), 6 (8), 7 (91) | 0 (2), 6 (9), 7 (89) | 0 (3), 6 (10), 7 (87) |
| **Foot** | 0 (1), 1 (60), 2 (39) | 0 (1), 1 (65), 2 (34) | 0 (2), 1 (68), 2 (30) | 0 (3), 1 (70), 2 (27) | 0 (4), 1 (72), 2 (24) |
| **Ankle** | 0 (1), 1 (60), 2 (39) | 0 (1), 1 (65), 2 (34) | 0 (2), 1 (67), 2 (31) | 0 (3), 1 (70), 2 (27) | 0 (3), 1 (72), 2 (25) |
| **Lower Leg** | 0 (1), 1 (60), 2 (39) | 0 (1), 1 (62), 2 (37) | 0 (2), 1 (65), 2 (33) | 0 (3), 1 (68), 2 (29) | 0 (4), 1 (70), 2 (26) |
| **Knee** | 0 (2), 1 (1), 2 (96), 3 (1) | 0 (2), 1 (2), 2 (95), 3 (1) | 0 (3), 1 (3), 2 (93), 3 (1) | 0 (4), 1 (3), 2 (92), 3 (1) | 0 (5), 1 (4), 2 (90), 3 (1) |
| **Upper Leg** | 0 (1), 1 (60), 2 (39) | 0 (1), 1 (62), 2 (37) | 0 (2), 1 (65), 2 (33) | 0 (3), 1 (67), 2 (30) | 0 (4), 1 (70), 2 (26) |
| **Hip** | 0 (1), 3 (2), 4 (97) | 0 (1), 3 (3), 4 (96) | 0 (1), 3 (4), 4 (95) | 0 (2), 3 (5), 4 (93) | 0 (3), 3 (6), 4 (91) |
| **Hand (Thumb side)** | 6 (13), 7 (87) | 6 (12), 7 (88) | 6 (11), 7 (89) | 6 (10), 7 (90) | 6 (9), 7 (91) |
| **Wrist (Placket)** | 6 (14), 7 (86) | 6 (13), 7 (87) | 6 (12), 7 (88) | 6 (11), 7 (89) | 6 (10), 7 (90) |
| **Lower Arm** | 4 (14), 5 (86) | 4 (13), 5 (87) | 4 (12), 5 (88) | 4 (11), 5 (89) | 4 (10), 5 (90) |
| **Upper Arm** | 6 (13), 7 (87) | 6 (12), 7 (88) | 6 (11), 7 (89) | 6 (10), 7 (90) | 6 (9), 7 (91) |
| **Shoulder** | 6 (13), 7 (87) | 6 (12), 7 (88) | 6 (11), 7 (89) | 6 (10), 7 (90) | 6 (9), 7 (91) |

**Table 2.22:** Discomfort Distribution and Severity by Body Part at Different Stages of the Shift in Standing CNC Operators (Levels 1-7)

| Body Part | Beginning of Shift | First Break | Lunch Break | After Lunch | End of Shift |
|---|---|---|---|---|---|
| **Abdomen** | 0 (3.5), 1 (62.8), 2 (33.7) | 0 (4.0), 1 (65.0), 2 (31.0) | 0 (5.0), 1 (67.0), 2 (28.0) | 0 (6.0), 1 (70.0), 2 (24.0) | 0 (7.0), 1 (73.0), 2 (20.0) |
| **Chest** | 0 (2.7), 1 (7.0), 3 (16.8) | 0 (3.0),1(8.0), 3 (19.0) | 0 (4.0), 1 (10.0), 3 (18.0) | 0 (5.0), 1 (12.0), 3 (17.0) | 0 (6.0), 1 (14.0), 3 (16.0) |
| **Neck** | 6 (7.1), 7 (92.9) | 6 (6.0), 7 (94.0) | 6 (5.0), 7 (95.0) | 6 (4.0), 7 (96.0) | 6 (3.0), 7 (97.0) |
| **Eyes** | 0 (3.5), 7 (96.5) | 0 (3.0), 7 (97.0) | 0 (2.5), 7 (97.5) | 0 (2.0), 7 (98.0) | 0 (1.5), 7 (98.5) |
| **Foot** | 0 (1.8), 6 (77.9), 7 (20.3) | 0 (2.0), 6 (76.0), 7 (22.0) | 0 (2.5), 6 (75.0), 7 (22.5) | 0 (3.0), 6 (74.0), 7 (23.0) | 0 (3.5), 6 (73.0), 7 (23.5) |
| **Ankle** | 1 (1.8), 6 (77.9), 7 (20.3) | 1 (2.0), 6 (76.0), 7 (22.0) | 1 (2.5), 6 (75.0), 7 (22.5) | 1 (3.0), 6 (74.0), 7 (23.0) | 1 (3.5), 6 (73.0), 7 (23.5) |
| **Lower Leg** | 0 (2.7), 6 (77.0), 7 | 0 (3.0), 6 (76.0), 7 | 0 (3.5), 6 | 0 (4.0), 6 | 0 (4.5), 6 |

| | | | | | |
|---|---|---|---|---|---|
| | (20.3) | (21.0) | (75.0), 7 (21.5) | (74.0), 7 (22.0) | (73.0), 7 (22.5) |
| **Knee** | 6 (10.0), 7 (90.0) | 6 (9.0), 7 (91.0) | 6 (8.0), 7 (92.0) | 6 (7.0), 7 (93.0) | 6 (6.0), 7 (94.0) |
| **Upper Leg** | 0 (3.5), 6 (79.7), 7 (16.8) | 0 (4.0), 6 (78.0), 7 (18.0) | 0 (4.5), 6 (77.0), 7 (18.5) | 0 (5.0), 6 (76.0), 7 (19.0) | 0 (5.5), 6 (75.0), 7 (19.5) |
| **Hip** | 0 (1.8), 6 (91.2), 7 (7.0) | 0 (2.0), 6 (90.0), 7 (8.0) | 0 (2.5), 6 (89.0), 7 (8.5) | 0 (3.0), 6 (88.0), 7 (9.0) | 0 (3.5), 6 (87.0), 7 (9.5) |
| **Hand (Thumb side)** | 0 (2.7), 1 (77.0), 2 (20.3) | 0 (3.0), 1 (76.0), 2 (21.0) | 0 (3.5), 1 (75.0), 2 (21.5) | 0 (4.0), 1 (74.0), 2 (22.0) | 0 (4.5), 1 (73.0), 2 (22.5) |
| **Wrist (Placket)** | 0 (2.7), 3 (71.7), 4 (25.6) | 0 (3.0), 3 (70.0), 4 (27.0) | 0 (3.5), 3 (69.0), 4 (27.5) | 0 (4.0), 3 (68.0), 4 (28.0) | 0 (4.5), 3 (67.0), 4 (28.5) |
| **Lower Arm** | 0 (6.2), 2 (28.3), 3 (6.2) | 0 (7.0), 2 (30.0), 3 (6.0) | 0 (7.5), 2 (31.5), 3 (6.0) | 0 (8.0), 2 (32.0), 3 (6.0) | 0 (8.5), 2 (32.5), 3 (6.0) |
| **Upper Arm** | 0 (2.7), 1 (75.2), 2 (22.1) | 0 (3.0), 1 (74.0), 2 (23.0) | 0 (3.5), 1 (73.0), 2 (23.5) | 0 (4.0), 1 (72.0), 2 (24.0) | 0 (4.5), 1 (71.0), 2 (24.5) |
| **Shoulder** | 0 (1.8), 6 (78.8), 7 (19.4) | 0 (2.0), 6 (77.0), 7 (21.0) | 0 (2.5), 6 (76.0), 7 (21.5) | 0 (3.0), 6 (75.0), 7 (22.0) | 0 (3.5), 6 (74.0), 7 (22.5) |

discomfort at level 2, and 16.8% experiencing moderate discomfort at level 3, indicating notable discomfort in the chest area. For the neck, the majority of operators (92.9%) experience high discomfort at level 7, pointing to severe strain in this area, likely due to prolonged awkward postures. Similarly, the eyes also show a high discomfort distribution, with 96.5% of operators reporting discomfort at level 7, indicating eye strain, possibly from continuous focus on tasks.

The foot, ankle, and lower leg areas exhibit high discomfort, with the majority (77.9%, 77.9% and 77.0% respectively) reporting discomfort at level 6, followed by 20.3% at level 7, indicating high strain causes severe discomfort. For the knee, 90.0% of operators report discomfort at level 7, showing that knee strain is significant higher levels of discomfort. Upper leg discomfort is also high, with 79.6% of operators reporting discomfort at level 6, and smaller percentage (16.8%) at level 7. In the hip region, the majority (91.2%) experience discomfort at level 6, indicating high discomfort levels, with a smaller percentage (7.0%) reporting severe discomfort at level 7. The hand (thumb side) shows a similar discomfort pattern to the foot and ankle, with 77.0% reporting discomfort at level 1, and 20.3% at level 2. For the wrist (placket side), discomfort is more pronounced, with 71.7% reporting discomfort at level 3, and 25.6% at level 4, indicating

significant wrist strain. The lower arm shows a more diverse distribution of discomfort, with 59.3% reporting level 1 discomfort, 28.3% at level 2, and smaller percentages at levels 0 and 3. Similarly, the upper arm follows a pattern of moderate discomfort, with 75.2% at level 1, and 22.1% at level 2. Finally, discomfort in the shoulder is primarily high, with 78.8% of operators at level 6 and 19.5% at level 7, showing significant strain causes severe discomfort. Overall, this data highlights the need for ergonomic interventions in several key body parts, particularly the shoulder, lower leg, upper leg, foot, knee, neck, eyes, ankle, and hip, to alleviate the discomfort experienced by CNC machine operators.

The Table 2.21 shows analysis of discomfort distribution among seated CNC operators reveals that severe discomfort is most prominent in the neck, eyes, upper arms, and shoulders throughout the shift, with little improvement, indicating a need for ergonomic intervention focused on upper body posture. The abdomen, chest, lower leg, upper leg, foot, and ankle show a gradual shift from moderate discomfort at the beginning of the shift to mild discomfort by the end, suggesting fatigue but lower severity. The knee and hip areas experience consistently high discomfort, with the knee showing minimal change and the hip seeing slight improvement. Prolonged seated work seems to cause persistent discomfort, especially in the upper body, while lower body discomfort tends to decrease slightly over time. To address these issues, ergonomic adjustments, more frequent breaks, and supportive equipment are recommended to reduce overall discomfort and improve operator well-being during their shifts.

Table 2.22 presents the discomfort analysis for standing CNC operators shows that discomfort levels generally increase throughout the shift, especially in the neck, eyes, knees, and shoulders. The neck and eyes consistently experience high levels of discomfort, with over 90% of operators reporting severe discomfort by the end of the shift. Lower body areas like the abdomen, foot, ankle, and lower leg show a gradual rise in discomfort, especially at moderate levels (1-2). Upper body areas such as the hand, wrist, lower arm, upper arm, and shoulder also show a steady increase in discomfort, particularly at severe levels (6-7) by the end of the shift. Overall, the findings highlight the need for ergonomic machine interface improvements and more frequent breaks to reduce discomfort and fatigue during shifts.

## 3. RESULTS

### 3.1. Occurrence of WMSDs in CNC Operators in Seated & Standing Postures

Work-related musculoskeletal disorders (WMSDs) among CNC operators show significant variation between seated and standing postures. According to the RULA assessment, 38.46% of seated operators experienced very high discomfort (RULA score of 7), and 23.08% reported severe discomfort (RULA score of 5-6) (Table 2.15). In contrast, standing operators displayed a more balanced distribution, with 38.76% reporting no discomfort, while 23.42% experienced slight pain, and 18.91%, 11.71%, and 7.20% reported very high discomfort (Table 2.18).

Despite the discomfort being more severe for seated operators, standing operators also reported significant discomfort in areas like the knees and feet, suggesting a notable occurrence of WMSDs in both postures due to static positions, repetitive movements, and insufficient ergonomic support. The overall WMSD claims for seated operators were 15% higher than those for standing operators, indicating a higher risk of musculoskeletal disorders among seated CNC operators (Lasota & Hankiewicz, 2017)(Muthukumar et al., 2012)(Muthukumar et al., 2012).

### 3.2. Body Part Discomfort by the End of the Shift

The discomfort experienced by CNC operators, both seated and standing, varies significantly throughout the shift, with notable increases by the end of the workday. For seated operators, severe discomfort (levels 6-7) predominantly affects the upper body, especially in the neck (91.1%), eyes (90.1%), hands (92.0%), wrists (91.1%), and shoulders (91.9%). This suggests that tasks performed in a seated position place a considerable strain on the upper body. Similarly, discomfort in the upper and lower arms is prominent, with 90.3% of operators reporting severe discomfort. Moderate discomfort (levels 1-2) is common in areas like the abdomen, foot, and lower leg, where 78-80% of operators report mild pain. Notably, 91.2% of operators experience moderate knee discomfort, indicating stress on lower extremities despite the seated posture. Discomfort in the chest and hips show more variation, with significant proportions of operators reporting discomfort levels between 2-4.

For standing operators, the neck (92.9%), eyes (96.5%), and knees (90.0%) experience the most severe discomfort by the end of the shift. The hips also show high discomfort levels (91.2%), with the lower leg, ankle, and foot experiencing moderate to severe discomfort (77-79%). Moderate discomfort is prevalent in the abdomen, chest, and upper arms, with 62.8% of operators reporting mild abdominal discomfort. The discomfort profile in the chest shows variability, with some experiencing discomfort at level 2, while others report higher levels.

In summary, both seated and standing operators face significant discomfort by the end of the shift, with seated operators primarily experiencing upper body strain and standing operators reporting more severe discomfort in the neck, eyes, and knees. These findings suggest that both postures lead to considerable physical strain, requiring interventions to mitigate the discomfort experienced throughout the workday.(Charles et al., 2017)(Afshari et al., 2018)

### 3.3. Work Performed by Seated and Standing Operators: Rates of Perceived Physical Exertion

The rates of perceived physical exertion for both seated and standing CNC operators reflect the physical demands associated with each posture during their work shifts. Seated operators often experience strain in their upper body due to repetitive tasks that involve the hands, arms, shoulders, and neck. This leads to high perceived exertion rates, particularly in these areas, as operators must frequently maintain static postures while performing precise tasks, such as handling tools and operating controls. Despite being seated, the lack of movement contributes to muscular fatigue, especially in the upper extremities, causing significant discomfort. (Halim et al., 2012)(Muthukumar et al., 2012)

Standing operators, on the other hand, face different physical challenges. They report higher exertion rates in the lower body, particularly in the legs, knees, hips, and feet. Prolonged standing places continuous pressure on the lower extremities, resulting in discomfort and fatigue. Additionally, operators who alternate between standing and slight bending or reaching motions often experience strain in both the lower and upper body, with perceived exertion spreading across the neck, shoulders, and back as well. Although standing allows for more flexibility and mobility compared to seated work, the cumulative impact of prolonged standing still leads to significant physical fatigue.(Le & Marras, 2016)

In both postures, the work performed by CNC operators involves repetitive, precise movements that contribute to overall physical exertion. While seated operators tend to report higher exertion rates in the upper body, standing operators primarily feel the strain in their lower body, highlighting the need for ergonomic solutions tailored to the specific demands of each working posture (Konz & Rys, 2003).

### 3.4. Problems Related to and Suggested Improvements to Reduce WMSDs

Several problems were identified as key contributors to WMSDs among CNC operators. For seated operators, prolonged static postures led to significant discomfort in the upper body, particularly the abdomen, chest, neck, and shoulders. Repetitive tasks and poor seating ergonomics likely contributed to these issues. On the other hand, standing operators faced challenges related to prolonged standing, which caused discomfort in the knees, feet, and lower back.

To reduce WMSDs, several ergonomic interventions are recommended. For seated operators, the use of adjustable seating with better lumbar support and periodic posture shifts could help alleviate discomfort in the upper body. The regular breaks to alternate between sitting and standing can reduce strain on the lower extremities. Additionally, both groups would benefit from ergonomic workstation designs that reduce repetitive hand and arm movements, particularly in the wrist and shoulder areas, as well as frequent breaks for stretching and movement to mitigate long-term discomfort and reduce the risk of musculoskeletal disorders.

## 4. DISCUSSION

This study investigates the ergonomic risks associated with seated and standing postures among CNC operators, revealing significant discomfort levels that are critical for understanding the prevalence of work-related musculoskeletal disorders (WMSDs). Our findings indicate a marked difference in discomfort distribution between seated and standing operators, with both groups experiencing considerable strain in specific body parts. (Milani & Monteiro, 2012)

### 4.1. Discomfort Assessment and Body Posture

The Discomfort Assessment and Body Posture analysis in this study focused on evaluating various work postures of seated and standing CNC operators during tasks such as load lifting, tool fixing, control panel operation, work observation, and job loading/unloading. The study utilized structured interviews and questionnaires over the course of a year to collect data from operators. The yearly occurrences of Work-Related Musculoskeletal Disorder (WMSD) claims were calculated and analyzed using descriptive statistics, correlation, and statistical tests such as independent samples t-test and one-way ANOVA (Muthukumar et al., 2012; Hafiz et al., 2013; Ismaila et al., 2020).

Key demographic factors such as age, weight, height, and body mass index were measured alongside discomfort ratings using tools like measuring tape and goniometers. The discomfort ratings, especially in body parts such as the neck, shoulder, upper and lower arms, and wrists, were significant, indicating strain due to repetitive overhead tasks and poor postures. RULA assessments were also conducted to evaluate awkward postures for both seating and standing operators. Seated operators often bent their trunk and twisted their necks and arms during tasks, resulting in high RULA scores and corresponding discomfort levels. Similarly, standing operators exhibited significant discomfort in the shoulders, lower legs, and knees due to prolonged static postures. The findings highlight the critical need for ergonomic interventions to reduce discomfort and the risk of musculoskeletal disorders, particularly in areas like the neck, shoulder, upper limbs, and lower body (Kee, 2002; Yang et al., 2009).

### 4.2. Correlation between Work Tasks and Discomfort

The CNC operators reveals a strong relationship between specific tasks and the onset of discomfort, particularly in the upper body. Tasks such as load lifting, tool fixing, operating control panels, and job loading/unloading were found to impose significant strain on body parts like the neck, shoulders, upper arms, and wrists. Statistical analysis using independent samples t-tests and one-way ANOVA demonstrated significant discomfort in these areas, especially for tasks requiring repetitive overhead motions and prolonged static postures (Dev et al., 2018; Hafiz et al., 2013). RULA postural assessments further highlighted awkward body positions, particularly in seated operators who frequently bent their trunk, twisted their neck, and strained their upper limbs, resulting in high RULA scores (6-7) and elevated discomfort levels. The shoulder, in particular, showed the highest level of discomfort ($F=116.96$, $P<0.00$), followed by significant strain in the upper and lower arms, neck, and wrists (Kee, 2002). The correlation between these work tasks and discomfort underscores the need for ergonomic interventions to reduce musculoskeletal strain and improve working conditions for CNC operators.

### 4.3. Statistical Analysis and Ergonomic Implications

This study provides crucial insights into the discomfort experienced by CNC operators during various work tasks. The data analysis, using tools like SPSS for descriptive statistics and correlation tests, revealed significant levels of discomfort in key body parts, particularly the shoulders, upper arms, neck, and wrists. One-way ANOVA results highlighted the shoulder as the most impacted, with a high level of statistical significance ($F=116.96$, $P<0.00$), followed by the upper arm ($F=42.761$, $P<0.00$) and neck ($F=4.584$, $P=0.012$), indicating strong links between these areas and work-related tasks (Dev et al., 2018). The RULA assessment further demonstrated that poor posture and repetitive overhead movements contributed to elevated ergonomic risks, with many operators scoring 6-7, signaling an immediate need for intervention. The ergonomic implications of these findings are substantial, suggesting that without proper workstation adjustments, frequent breaks, and improved task design, CNC operators are at high risk of developing long-term musculoskeletal disorders (WRMSDs). These results emphasize the importance of targeted ergonomic strategies to reduce strain, improve postures, and enhance the overall safety and comfort of CNC machine operations.

### 4.4. Recommendations for Ergonomic Improvements

To mitigate the risks of WMSDs among CNC operators, we recommend several ergonomic interventions. For seated operators, the introduction of adjustable seating with adequate lumbar support, alongside training on proper posture, could alleviate discomfort in the upper body. For standing operators, implementing anti-fatigue mats and promoting supportive footwear could reduce lower limb strain. Regular breaks to alternate between sitting and standing are essential for both groups, as they can help mitigate cumulative fatigue and discomfort. Additionally, redesigning workstations to minimize repetitive movements, particularly in the wrist and shoulder regions, is crucial. Implementing job rotation and stretching exercises can further enhance overall worker comfort and health. (Tröster et al., 2020)

## 5. CONCLUSION

This study provides a comprehensive analysis of the ergonomic risks faced by CNC operators in both seated and standing postures, highlighting the prevalence of discomfort and the potential for work-related musculoskeletal disorders (WMSDs). The significant discomfort levels reported by operators in critical body areas, particularly the neck, shoulders, abdomen, and wrists, underscore the urgent need for targeted ergonomic interventions.

Our findings reveal a strong correlation between specific work tasks and discomfort levels, emphasizing the impact of awkward postures and repetitive motions on operator health. The statistical analysis further confirms that both seated and standing postures contribute to distinct discomfort patterns, necessitating a dual approach to ergonomic improvements. For seated operators, enhancing workstation design with adjustable seating and proper lumbar support is vital, while standing operators can benefit from anti-fatigue mats and appropriate footwear.

Moreover, the implementation of regular breaks, job rotation, and stretching exercises can significantly alleviate cumulative fatigue and discomfort. These ergonomic interventions not only aim to reduce discomfort but also promote overall worker health, productivity, and job satisfaction.

In conclusion, the findings of this research stress the importance of a proactive approach to ergonomics in CNC operations. By prioritizing the well-being of operators and addressing the specific discomforts associated with their work environments, we can contribute to a healthier, safer, and more efficient manufacturing landscape. Future studies should continue to assess the long-term effects of these ergonomic strategies, providing a roadmap for continuous improvement in operator health and safety.

## 6. RELEVANCE TO INDUSTRY

This study highlights the critical need for ergonomic improvements in CNC machine design to accommodate both able-bodied and wheelchair-bound operators. Addressing ergonomic risk factors such as poor posture, repetitive motions, and machine inaccessibility can significantly reduce Work-Related Musculoskeletal Disorders (WMSDs), improving worker safety and productivity. By implementing inclusive design modifications, manufacturers can enhance operational efficiency, reduce downtime due to operator discomfort, and create a more accessible work environment. These changes are essential for fostering a more inclusive industrial workforce and ensuring compliance with occupational safety standards.

## ACKNOWLEDGEMENTS

This research is under research Proposal Scheme (RPS) AICTE (All India Council for Technical Education) by the authors.

## REFERENCES

[1] **Afshari, D., Mazloumi, A., Nourollahi-Darabad, M., Saraji, G N., & Foroushani, A R. (2018, April 30).** Effect of neck posture on cervicothoracic loads in overhead crane operators. Taylor & Francis, 27(1), 316-322. https://doi.org/10.1080/10803548.2018.1458436

[2] **Cameron, J A. (1996, December 1).** Assessing work-related body-part discomfort: Current strategies and a behaviorally oriented assessment tool. Elsevier BV, 18(5-6), 389-398. https://doi.org/10.1016/0169-8141(95)00101-8

[3] **Chandna, P., Deswal, S., & Chandra, A. (2010, January 1).** An anthropometric survey of industrial workers of the northern region of India. Inderscience Publishers, 6(1), 110-110. https://doi.org/10.1504/ijise.2010.034000

[4] **Charles, L E., Claudia, C., Burchfiel, C M., & Dong, R G. (2017, October 28).** Vibration and Ergonomic Exposures Associated With Musculoskeletal Disorders of the Shoulder and Neck. Elsevier BV, 9(2), 125-132. https://doi.org/10.1016/j.shaw.2017.10.003

[5] **Chatterjee, A., & Sahu, S. (2018, April 13).** A physiological exploration on operational stance and occupational musculoskeletal problem manifestations amongst construction labourers of West Bengal, India. IOS Press, 31(4), 775-783. https://doi.org/10.3233/bmr-170935

[6] **Corlett, E., & Bishop, R P. (1976, March 1).** A Technique for Assessing Postural Discomfort. Taylor & Francis, 19(2), 175-182. https://doi.org/10.1080/00140137608931530

[7] **Delvolvé, N., & Quéinnec, Y. (1983, April 1).** Operator's activities at CRT terminals: a behavioural approach. Taylor & Francis, 26(4), 329-340. https://doi.org/10.1080/00140138308963349

[8] **Denkena, B., Klemme, H., Becker, J., & Blech, H. (2022, April 16).** User-Specific Parameterization of Process Monitoring Systems. Springer Science+Business Media, 16(6), 735-742. https://doi.org/10.1007/s11740-022-01130-1

[9] **Dev, M., Bhardwaj, A., & Singh, S. (2018, January 1).** Analysis of work-related musculoskeletal disorders and ergonomic posture assessment of welders in unorganised sector: a study in Jalandhar, India. , 5(3), 240-240. https://doi.org/10.1504/ijhfe.2018.095913

[10] **Erliana, K., Kautsar, F., Oktaviani, D., Yuniawan, D., Hariyanto, S., Andriono, D., Mohamad, E., & Firdiansyah, R. (2019, January 1).** Solving Office Ergonomics Problem Using Rapid Upper Limb Assessment (RULA). https://doi.org/10.2991/icoemis-19.2019.3

[11] **García-Sabater, J P., Maheut, J., Ruiz, Á., & Sabater, J J G. (2020, November 21).** A Framework for Capacity and Operations Planning in Services Organizations Employing Workers with Intellectual Disabilities. Multidisciplinary Digital Publishing Institute, 12(22), 9713-9713. https://doi.org/10.3390/su12229713

[12] **Guha, S K., & Anand, S. (1980, April 1).** A System to Enable the Blind to Work Independently on the Center Lathe. SAGE Publishing, 74(4), 136-141. https://doi.org/10.1177/0145482x8007400403

[13] **Hafiz, M Z., Halim, I., & Mohamed, M S S. (2013, December 30).** An Overview of Ergonomics Problems Related to CNC Machining Operations. , 10, 137-142. https://doi.org/10.4028/www.scientific.net/aef.10.137

[14] **Halim, I., Omar, A R., Saman, A M., & Othman, I. (2012, March 1).** Assessment of Muscle Fatigue Associated with Prolonged Standing in the Workplace. Elsevier BV, 3(1), 31-42. https://doi.org/10.5491/shaw.2012.3.1.31

[15] **Hussen, J., Dagne, H., & Yenealem, D G. (2020, April 27).** Factors Associated with Occupational Injury among Hydropower Dam Construction Workers, South East Ethiopia, 2018. Hindawi Publishing Corporation, 2020, 1-9. https://doi.org/10.1155/2020/6152612

[16] **Ismaila, S O., Oriolowo, T K., Kuye, S I., Adekunle, N O., Adewumi, B A., & Alabi, A A. (2020, April 3).** Ergonomic risk assessment of maintenance job in a gas power station. , 62(1), 47-60. https://doi.org/10.31306/s.62.1.1

[17] **Kee, D. (2002, January 1).** A method for analytically generating three-dimensional isocomfort workspace based on perceived discomfort. Elsevier BV, 33(1), 51-62. https://doi.org/10.1016/s0003-6870(01)00047-3

[18] **Khan, I A. (2014, January 1).** Multi-response ergonomic evaluation of female CNC machine operators. , 3(1), 32-32. https://doi.org/10.1504/ijhfe.2014.062549

[19] **Konz, S., & Rys, M J. (2003, September 11).** An ergonomics approach to standing aids. IOS Press, 3(3), 165-172. https://doi.org/10.3233/oer-2003-3303

[20] **Krishnan, C., Sandhyavarshini, R., & Jeyakumar, V. (2021, June 1).** Non – Clinical Pain Assessment System – A Pilot Study. IOP Publishing, 1917(1), 012008-012008. https://doi.org/10.1088/1742-6596/1917/1/012008

[21] **Kwon, C. (2020, October 28).** Resisting ableism in deliberately developmental organizations: A discursive analysis of the identity work of employees with disabilities. Wiley, 32(2), 179-196. https://doi.org/10.1002/hrdq.21412

[22] **Lasota, A., & Hankiewicz, K. (2017, January 1).** The study of postural workload in assembly of furniture upholstery. EDP Sciences, 137, 07002-07002. https://doi.org/10.1051/matecconf/201713707002

[23] **Le, P., & Marras, W S. (2016, September 1).** Evaluating the low back biomechanics of three different office workstations: Seated, standing, and perching. Elsevier BV, 56, 170-178. https://doi.org/10.1016/j.apergo.2016.04.001

[24] **Liu, L., Li, W., Tan, Z., Zhang, M., & Bo, M. (2019, July 1).** Model design and analysis improvement of CNC Lathe Based on Ergonomics. IOP Publishing, 573(1), 012045-012045. https://doi.org/10.1088/1757-899x/573/1/012045

[25] **Lop, N S., Salleh, N M., Zain, F M Y., & Saidin, M T. (2019, September 20).** Ergonomic Risk Factors (ERF) and their Association with Musculoskeletal Disorders (MSDs) among Malaysian Construction Trade Workers: Concreters. , 9(9). https://doi.org/10.6007/ijarbss/v9-i9/6420

[26] **Lu, X. (2013, January 1).** Study on Modeling Design of CNC Machine Tool Based on Ergonomics. Trans Tech Publications, 274, 7-10. https://doi.org/10.4028/www.scientific.net/amm.274.7

[27] **Majumder, C. (2019, February 28).** Prevalence of Disabled People in India. Rekha Patel, Volume-3(Issue-2), 846-851. https://doi.org/10.31142/ijtsrd21495

[28] **Marino, D J., Rivera, V., Joseph, J., Williams, R L., Jeannis, H., Goldberg, M., Grindle, G G., Kimmel, J., & Cooper, R A. (2019, February 27).** Accessible machining for people who use wheelchairs. IOS Press, 62(2), 361-370. https://doi.org/10.3233/wor-192870

[29] **Milani, D., & Monteiro, M S. (2012, January 1).** Musculoskeletal symptoms and work ability among agricultural machinery operators. IOS Press, 41, 5721-5724. https://doi.org/10.3233/wor-2012-0930-5721

[30] **Mistarihi, M Z. (2020, March 12).** A data set on anthropometric measurements and degree of discomfort of physically disabled workers for ergonomic requirements in work space design. Elsevier BV, 30, 105420-105420. https://doi.org/10.1016/j.dib.2020.105420

[31] **Muthiah, A., Singh, A K., & Karmakar, S. (2020, March 24).** Determination of the key anthropometric and range of motion measurements for the ergonomic design of motorcycle. Elsevier BV, 159, 107751-107751. https://doi.org/10.1016/j.measurement.2020.107751

[32] **Muthukumar, K., Sankaranarayanasamy, K., & Ganguli, A K. (2012, June 1).** Discomfort Analysis in Computerized Numeric Control Machine Operations. Elsevier BV, 3(2), 146-153. https://doi.org/10.5491/shaw.2012.3.2.146

[33] **Muthukumar, K., Sankaranarayanasamy, K., & Ganguli, A K. (2012, May 2).** Analysis of Frequency, Intensity, and Interference of Discomfort in Computerized Numeric Control Machine Operations. Wiley, 24(2), 131-138. https://doi.org/10.1002/hfm.20357

[34] **Özcan, A G. (2021, September 29).** Ergonomic Risk Assessment in Automotive Welding Lines and Comparison of Method Output. , 645-659. https://doi.org/10.24012/dumf.1002172

[35] **Salam, Z A., Bakar, L J A., Mansor, N N A., & Amran, N A. (2021, September 27).** Can Disable Person be Transformed Positively?. , 11(3). https://doi.org/10.6007/ijarafms/v11-i3/10924

[36] **Segar, G., & Rahman, M N A. (2019, August 1).** Musculoskeletal symptoms and ergonomic risk assessment among production operators at manufacturing industries: A review. IOP Publishing, 607(1), 012009-012009. https://doi.org/10.1088/1757-899x/607/1/012009

[37] **Soewardi, H., & Afgani, M K A. (2019, August 1).** Innovative Design of Ergonomic Wheelchair For Disabled People. IOP Publishing, 598(1), 012033-012033. https://doi.org/10.1088/1757-899x/598/1/012033

[38] **Susihono, W., Selviani, Y., Dewi, I A K A., & Liswahyuningsih, N L G. (2020, January 1)**. Musculoskeletal and Postural Stress Evaluation as a Basic for Ergonomic Work Attitudes on Welding Workers. https://doi.org/10.2991/assehr.k.200115.044

[39] **Tröster, M., Wagner, D A., Müller-Graf, F., Maufroy, C., Schneider, U., & Bauernhansl, T. (2020, July 16).** Biomechanical Model-Based Development of an Active Occupational Upper-Limb Exoskeleton to Support Healthcare Workers in the Surgery Waiting Room. Multidisciplinary Digital Publishing Institute, 17(14), 5140-5140. https://doi.org/10.3390/ijerph17145140

[40] **Wang, J., Hu, B., Ran, X., & Liu, G. (2010, July 1).** Design of drawing beeline machine based on monitor. https://doi.org/10.1109/indusis.2010.5565696

[41] **Wu, X L., Chen, H J., & Yao, Y. (2011, October 1).** Industrial Design and Analysis of Numerical Control Machine on Ergonomic. Trans Tech Publications, 121-126, 2049-2053. https://doi.org/10.4028/www.scientific.net/amm.121-126.2049

[42] **Yadav, R., Tewari, V K., & Prasad, N. (n.d).** Anthropometric data of Indian farm workers. https://www.sciencedirect.com/science/article/pii/S0003687096000221

[43] **Yang, Z., Sun, S., & Chen, G. (2009, November 1).** Evaluating sitting comfort with questionnaire and body pressure distribution: Overview and design. https://doi.org/10.1109/caidcd.2009.5375350

[44] **Zhao, Y S. (2021, September 1).** Analysis of Application of Numerical Control Technology in Mechanical Manufacturing. IOP Publishing, 2023(1), 012029-012029. https://doi.org/10.1088/1742-6596/2023/1/012029