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Enhancing Ergonomics in Automotive Cylinder Head Manual Lapping: Workstation Assessment and Design

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Human factors play a vibrant part in advancing health and yield at factories. In the last 20 years, ergonomic practitioners have given importance to reshaping the workroom. Indian businesses have also initiated reshaping their workroom to avoid several Work-related Musculoskeletal Disorders (WMSD) and grievances. In this background, the project has been carried out in an automotive reconditioning workshop located in Nagpur and Pune. The ergonomic risk associated with WMSD was recognized by a comprehensive questionnaire, which was received from 18 experienced workers engaged in cylinder head Manual lapping activity. It was found that virtually all lapping workers were continuously suffering from some kind of WMSD. Based on the anthropometric data of 50 percentile Indian males, ergonomic evaluation, reshaping the existing workplace, and evaluation of a new workstation were carried out in CATIA-V5 software. To check the correction of the design, Rapid Upper Limb Assessment (RULA) for both existing as well as proposed lapping workstations was performed. This study shows that improving workstations with a structured improvement framework approach decreases the disparity between man and machine and makes the workplace comfortable for work.

Keywords: Anthropometry, CATIA –V5, Musculoskeletal disorder, Rapid upper limb assessment, Workstation improvement

Introduction

The science of ergonomics focuses on matching the right person to the right job with the workstation in a controlled setting to optimize human productivity. Work system design is a difficult task since a designer must make sure that a man, his workstation, and the working environment are properly matched. Additionally, due to individual differences in body measurements, physical and mental capacities, and task needs, a particular workstation may not be appropriate for everyone.[1] Due to the mismatch between human anthropometry, workstation dimensions, and job differences, an issue of Work-related Musculoskeletal Diseases (WMSDs) arises.

The issue of WMSDs is particularly prevalent in the present industrial work environment. Low back pain is the most common ailment. Disorders of the muscles, tendons, tendon sheaths, peripheral nerves, joints, bones, ligaments, etc. are among the most frequent WMSDs. The accumulation of repetitive stress over time is the primary cause of Musculoskeletal Disorders (MSDs). Throughout the world, millions of people suffer from musculoskeletal disorders. The prevalence of MSDs varies widely over the world, from 14% to about 42%.[2] However, epidemiological studies show that up to 80% of studies in India revealed occupation-specific incidence, with a community-based prevalence of close to 20%.[3–7] It might be because emerging nations like India have a high reliance on the employment of labor because it is simple and inexpensive to do so. It is essential to raise public understanding of ergonomic dangers, their causes, and how to prevent them. If this isn't done, the risk to the workers varies from minimal to very high, depending on the difficulty and nature of the activity they are doing. The planner or designer of the workplace must, as a minimum requirement, take ergonomic factors into account and adhere to ergonomic principles. Industry groups in developing nations like India are becoming more concerned with preserving employees' wellbeing and lowering labor absenteeism for their competitiveness. Over the past two decades, it has been important to remodel the workplace since ergonomics plays a critical role in enhancing health and productivity.[8]

In order to address the problem of WMSDs, authors in the fields of human factors and/or ergonomics are frequently interested in identifying risks associated with work activities, postural loading,

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the effect of vibration, tool use, coupling, awkward postures, movement frequency and duration, work envelopes, ergonomic workstation design.[9]

The designers are employing a variety of workstation design strategies. However, there aren't many studies that cover how to make current workstations more productive and ergonomically sound. In order to increase an operator's comfort, the authors concentrated on incorporating the operator's opinion into the design of a cargo crane cabin workstation. The ergonomic design of a workstation is cited[10,11] as being necessary to address the issue of Musculoskeletal Disorders (MSDs) in workers in the future. Authors[13] looked at the risk variables connected with MSDs and their prevalence among Chinese nurses. They also noted that individual characteristics, working hours, gender, BMI, age, and alcohol usage had a substantial impact on the chance ratios of MSDs.

Numerous studies on ergonomic solutions have been conducted in the past. According to studies, aspects including human capabilities, working and resting times, posture, anthropometry, job sequencing, etc. have an impact on how well employees perform. However, the majority of studies looked at uncomfortable posture and human comfort for workstation design and improvement. When numerous variables interact to determine how well the employee performs, a structured strategy for workstation improvement is needed, but there doesn't seem to be one in the literature. Finding connections between the aspects influencing human performance is necessary for creating a structured approach.

This study aims at implementing a structured approach incorporating an interpretive structural modeling-based workstation improvement framework developed in earlier study.[13] The implementation of a workstation improvement framework is carried out for the lapping process of the cylinder head in an automobile reconditioning workshop located in Nagpur and Pune. The Worker performing Manual lapping operation has to perform various activities, such as continuous monitoring of the work surface, loading, and unloading of the heavy cylinder head, adjustment of stool position as per the valve, etc. The task of the lapping operator is highly repetitive.

Study Objectives

The study aims at investigating:

- Ergonomic assessment of cylinder head manual lapping activity in the automotive industry
- Proposing a new workstation design as per the improvement framework
- RULA analysis of lapping activity under existing and new workstations

Materials and Methods

The framework/methodology developed[13] is a generalized framework. Only the relevant factors were selected for this case which are shown in Fig. 1. The framework thus modified is used for the improvement of the manual lapping workstation. The modification is done in terms of critical success factors and methodology. The methodology now is made systematic showing correct flow from top to bottom. In earlier framework the flow of improvement was from bottom to top. The application of the modified framework is as follows:

Task Selection

Valve lapping is the process of creating a good seat between engine valves and the corresponding valve seat area in the internal combustion engine. This process of valve lapping is typically done using a valve lapping stick or a power tool. In the current scenario, the Existence of Manual work, No/Poorly designed workstations, Unhappy workers/absenteeism, Repetitive Motions, and Management concerns were present. Hence this workstation was the perfect fit for the implementation of the proposed framework. The average absenteeism noted was 5–10% workers. Due to absenteeism, the output was getting affected.

Data Collection

The duration of the study was around 8–10 months. Data in Table 1 provides the breakdown of activities involved in manual cylinder head lapping activity. The devices/tools/materials available in the existing scenario are also mentioned. In Fig. 2(a–g) various positions in which the operator works for a maximum number of times is shown.

Data Analysis

Musculoskeletal Disorder (MSD) Analysis

Musculoskeletal Questionnaire has been used to assess the nature and severity of musculoskeletal symptoms. A multiple-choice type questionnaire was constructed on similar lines to the earlier research,[14,15] for identifying and elaborating on the problems faced by 18 lapping workers in an automobile reconditioning workshop. The questionnaire enquires

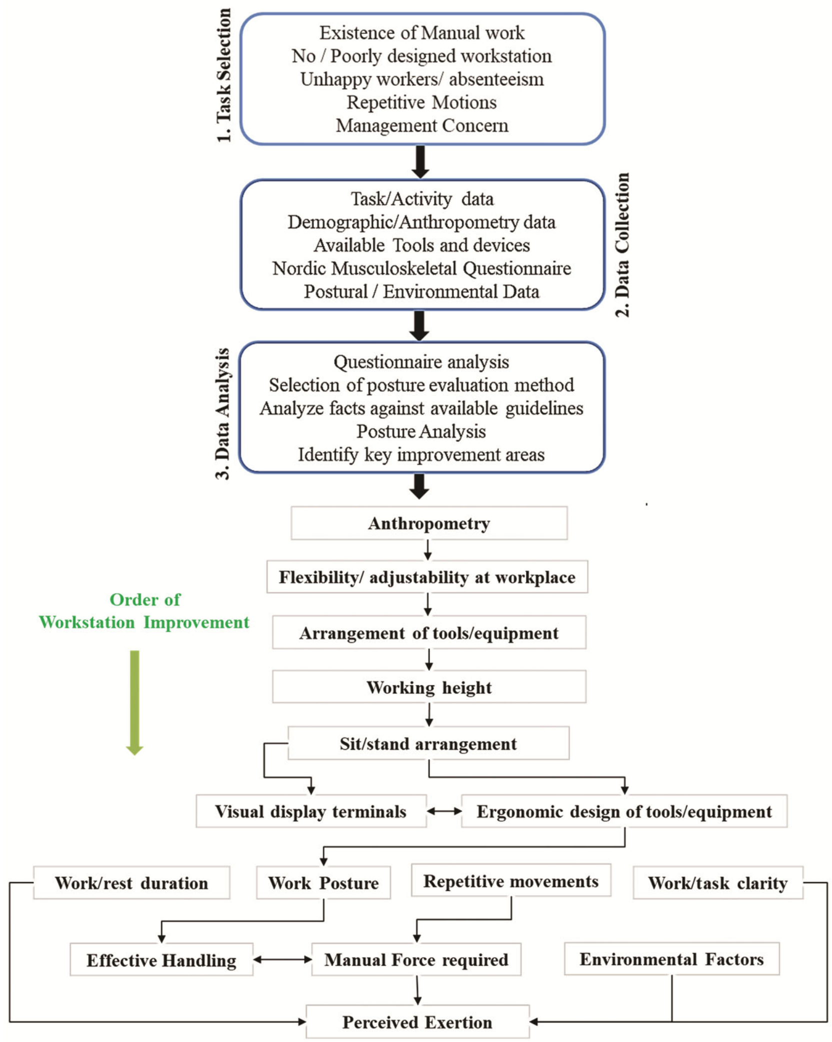

Fig. 1 — Workstation improvement framework

Table 1 — Activity involved and available tools/materials

S. No	Activity	Available tools/materials
1	Head loading	• Stand
2	Head cleaning	• Cotton / Cloth • Pneumatic supply line • Cleanser liquid • Cleaning tools/ sandpapers
3	Head Inspection	• Inspection gauges • Leveling stripe (Patti) • Boring bar
4	Valve and valve seat grinding	• Valves • Valve Cartoon • Valve seat cutter/grinder • Bench Grinder
5	Applying lapping compound	Fine/coarse-lapping compound
6	Manual lapping	Lapping sticks
7	Final Pneumatic Cleaning and inspection.	Pneumatic supply line

about the history of experience of musculoskeletal problems in nine body positions (neck, shoulders, elbows, wrists/hands, upper back, lower back, hips/thighs, knees, and ankles/feet) over the past weeks and over the past year.[16]

Anthropometric measurements of lapping workers were carried out as per the guidelines.[17] Referring to Table 2, it shows the general anthropometric dimensions of the sample (18 manual-lapping workers). A modified Borg scale[18] of range 1–10 was used to rate the perceived exertion and pain experienced by lapping workers. Over both time frames, neck pain, wrist/hands, lower back, thigh/hip, and knee pain were most frequently reported (Table 3). MSD analysis of lapping workers clearly indicates (Fig. 3) that 100% of workers continuously suffer from some kind of MSD. This study clearly demonstrates that the existing setup for lapping

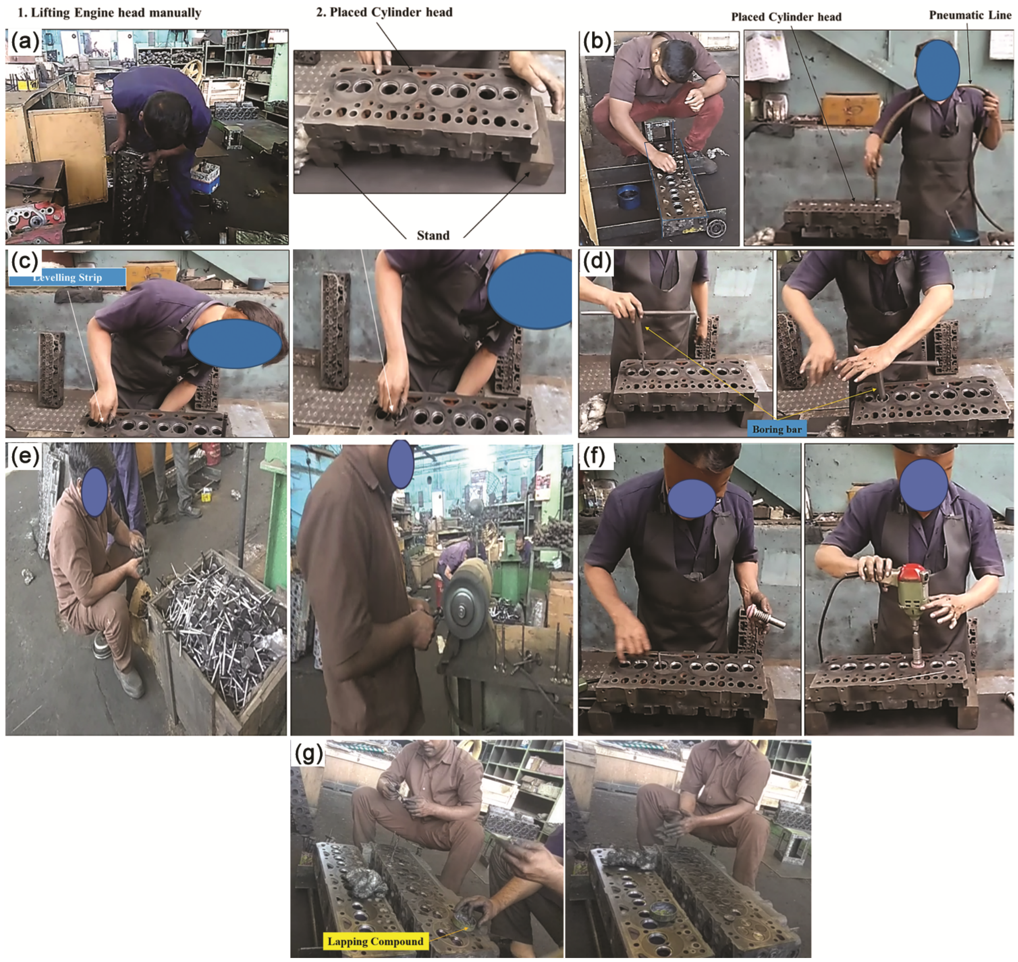

Fig. 2 — Various positions in which the operator works for a maximum number of times: (a) Lifting and placing cylinder head on stand, (b) Head cleaning, (c) Head inspection, (d) Valve seat cutting, (e) Valve selection and grinding, (f) Valve seat grinding (g) Application of lapping compound and lapping activity

Table 2 — Demographic characteristics

SN	Gender	Age	Height	Weight	Experience
1	M	42	5" 6	70	10
2	M	35	5" 8	80	7
3	M	21	5" 8	74	1
4	M	53	5" 5	69	20
5	M	48	5" 8	68	12
6	M	45	5" 11	78	10
7	M	21	5" 10	74	1
8	M	38	5" 9	75	8
9	M	43	5" 10	78	13
Average =		38.44	5"8	74	9.11
Max =		53	5" 11	80	20
Min =		21	5" 5	68	1

activity does not provide any comfort, convenience of use, or safety from the risks of MSD. Pareto Chart (Fig. 4) also indicates that major contributors to MSDs are wrist, neck, lower back, and one or both hips.

Table 3 — Observed prevalence rates for MSD

Area of the body affected	Occurrence in last 12 months (% of the sample)	Occurrence in last week (% of the sample)
Neck	88.89	56.78
Shoulders	66.67	43.45
Elbows	22.22	9.52
Wrists/hands	100.00	60.75
Upper back	44.44	85.18
Lower back	88.89	77.7
Hip/Thigh	77.78	70.69
Knee	55.56	20.87
Ankle/feet	22.22	5.50

Work Posture Analysis

The real-time observation of the lapping workers' postures was carried out to identify the most repetitive working postures. The duration of the postures was recorded and the work-rest cycles of the operators were analyzed. It was observed that lifting and placing the cylinder head on the stand (Fig. 2a) takes

5% of the total time, bending and looking down with arms below knee level posture takes 20% of the total time (Fig. 2b, left), bending left and looking down-left posture (Fig. 2c) takes 14% of the total time, posture involved in Valve Seat Cutting takes 9% of the total time, valve selection and grinding takes 3% of the total time (Fig. 2e), valve seat grinding takes 3% of the total time, and application of lapping compound and manual lapping activity takes the majority 46% of the total time. All of these postures involved bending of the back and arm stretching below the knee level.

The anthropometric database is the foundation for human body modeling. The data for stature and position during sitting collected in this study show that the stature lies between 157.5 and 167.3 cm with an average of 162.3 cm and a standard deviation is 4.8 cm. The sitting eye height lies between 70.2 and 74.8 cm with an average of 72.5 cm and a standard deviation is 2.3 cm. Based on these observations, stature and sitting eye height obtained from this study were compared with Indian anthropometric data.[19] It was found that the values for the worker's stature and average eye level during sitting posture lie within the acceptable range which is suitable for 50 percentile Indian manikin.

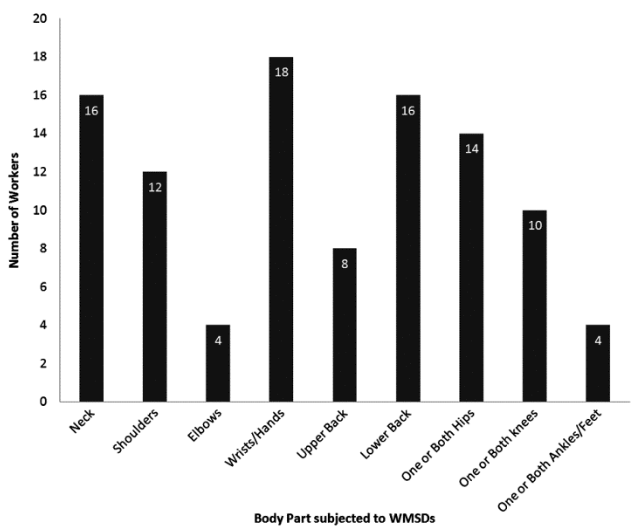

Fig. 3 — MSD risk vs number of workers

In order to identify the severity of posture, postural analysis was carried out by Rapid Upper limb assessment (RULA). The RULA examines the risk factors and all risk factors are combined to give a total score that ranges from 1 to 7.[(20)] The data displayed is combined with a color indicator zone. The color of this zone changes from green to red according to the total score. The score report consists of basic mode and advanced mode. In the basic mode, the scores 1 and 2 (Green color) indicates that the posture is acceptable if it is not maintained or repeated for long periods of time. The scores 3 and 4 (Yellow color) indicates that further investigation is needed and changes may be required. The scores 5 and 6 (Orange color) indicate that investigation and changes are required soon. The score 7 (Red color) indicates that investigation and changes are required immediately.

The RULA of cylinder head loading is shown in Fig. 5a. The final score obtained is 7 concluding investigate and change immediately. In this activity, the trunk is indicated with red color indicating a dangerous situation. Similarly, wrist, force/load, wrist, and arm are indicated by an orange color indicating a possibly dangerous situation. Fig. 5b shows the RULA analysis of the cleaning task. The final score obtained is 6 concluding investigate and change soon. In this activity, muscle and trunk score

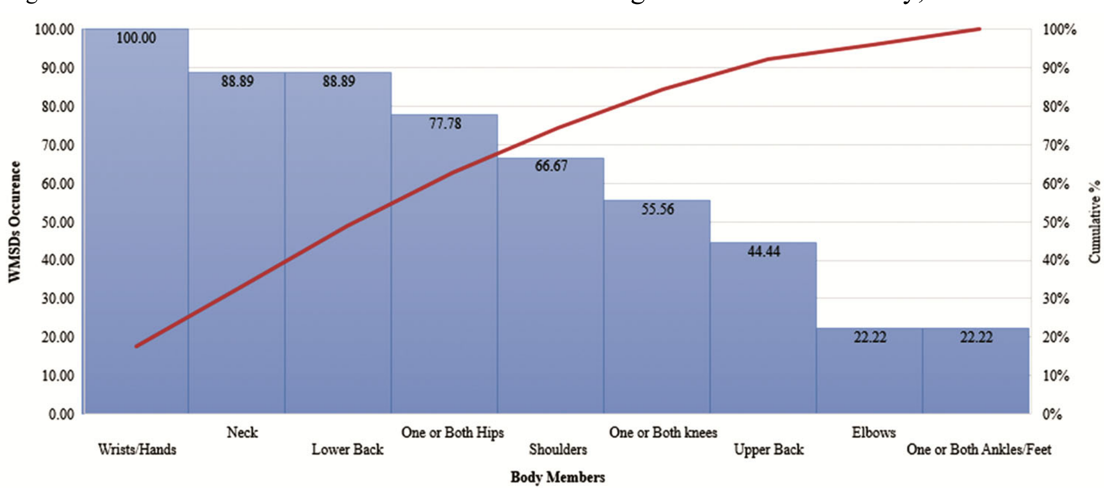

Fig. 4 — Pareto chart

Fig. 5 — RULA analysis of: (a) Loading task, (b) cleaning task

Table 4 — Comparison of posture analysis in existing and proposed workstation

S. No.	Operation	RULA Score (Existing)	RULA Score (Proposed)
1	Head loading	7	3
2	Cleaning	6	3
3	Inspection	6	5
4	Valve selection	5	3
5	Valve grinding	3	3
6	Valve seat hand boring	5	3
7	Valve seat cutting/grinding	5	3
8	Apply lapping compound	5	3
9	Manual lapping	6	3
	Average =	5.5	3.25

is indicated with red color indicating a dangerous situation. Similarly, RULA analysis was carried out for all the involved activities (refer to Table 4).

After discussion with the supervisor and managers, flexibility at the workplace, Visual display terminal/units, ergonomic design of tools/equipment, work duration, repetitive movements, work clarity, the manual force required, and environmental factors seemed either less dominant and/or non-existing, hence are neglected in improvement. Other factors are incorporated in improving the workstation.

Results

Interpretive Structural model-based workstation improvement is a stepwise improvement process. The stepwise results are covered below:

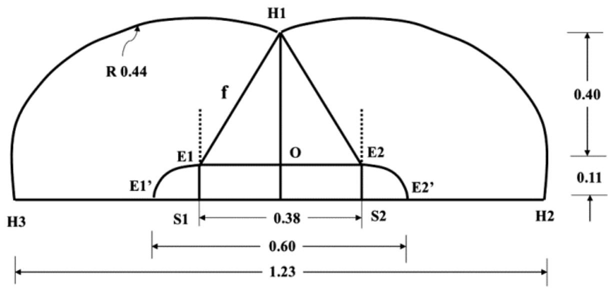

Fig. 6 — Normal reach zone for 50% Indian manikin[8] (Source: Kushwaha and Kane[8], 2015)

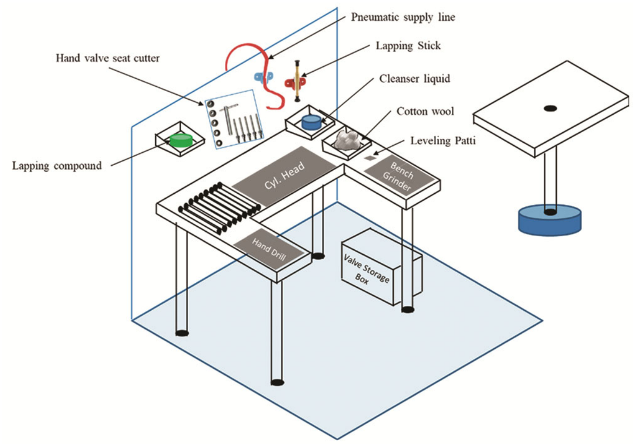

Fig. 7 — Isometric view of proposed workstation for lapping

1. **Anthropometry:** It starts with deciding and gathering the required anthropometry dimensions. The normal reach zone of 50% Indian manikin was prepared (Fig. 6) as per the guidelines.[21,22] When this reaching zone of 50 percentile Indian manikin was imposed on the actual workstation, it was found that the normal reach zone was unutilized in the existing lapping setup. In the proposed workstation, the concept of a normal reach zone was utilized and everything was placed within the normal reach zone.
2. **Arrangement of Tools/material:** Isometric view of the proposed workstation for lapping is shown in Fig. 7. As per Fig. 8, the most frequently used items are Cotton Wool (CW), Cleanser Liquid (CL), and Lapping Sticks (LS) placed on the right-hand side near to observed within the normal working zone and below eye level. The Lapping Compound (LC) is kept on the left side to engage the left and right hands equally. It follows the principle of motion economy to utilize both hands simultaneously. Less frequently used

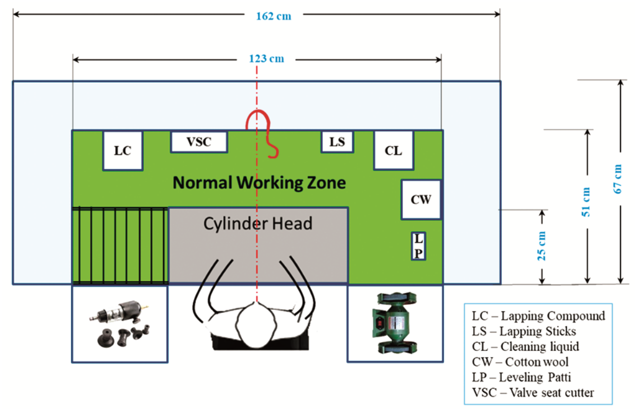

Fig. 8 — Arrangement of tools/materials

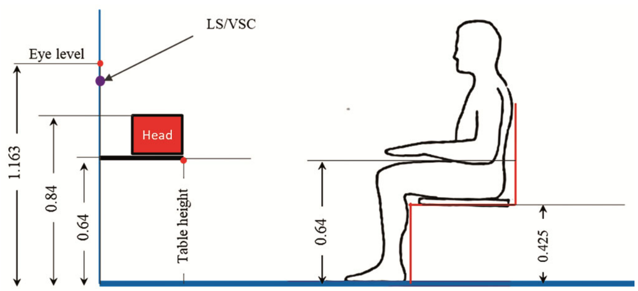

Fig. 9 — Working and seating height in the proposed workstation

items are the bench grinder, valve storage box, hand drill, and valve seat cutter are kept aside which may require turning the chair to the right/left side. The workpiece i.e. cylinder head is kept at the center of the table. The axis of the cylinder head, worker, and table coincides. The pneumatic pressure line is hung at the center for grabbing it with either the left or right hand as per availability.

3. **Working height and Sit-stand arrangement:** The table height is decided to be 0.64 m as per the standard data available for the Indian population. The working height for lapping is 0.84 m considering the height of the cylinder head which is placed on the table. The sitting height is considered 0.425 m for the Indian population as shown in Fig. 9.
4. **Work posture:** Due to the dependency of work posture on the above factors like anthropometry, arrangement of Tools/material, working height, and Sit-stand arrangement the work posture is already taken care of. The improved posture along with an improved RULA score can be observed in Fig. 10 (a & c) respectively.
5. **Effective load/material handling:** The hydraulic lifter can be used to lift the engine head up to the table height. The rollers are incorporated into the design so that push-slide movement can be obtained. The operator now loads and handles the material with ease.

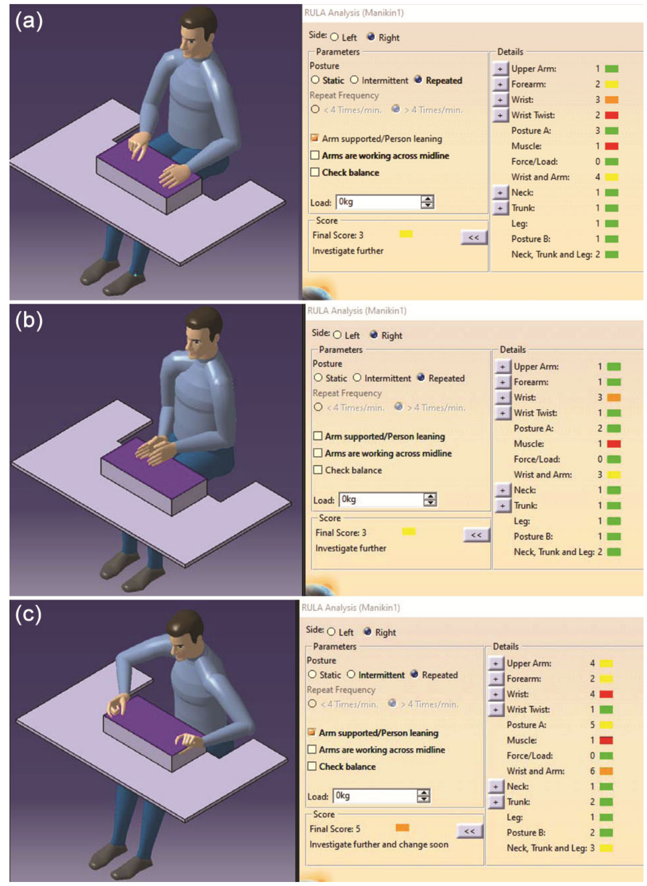

Fig. 10 — Improved postural score for: (a) cleaning task, (b) lapping task, (c) Inspection task

6. **Perceived exertion:** After implementing the improvement measures, it is to be believed that the perceived exertion must be reduced due to less bending, no awkward postures, no movement between different stations for bringing tools, grinding, etc. The reduction in perceived exertion needs to be validated after making the proposed workstation.

Discussion

Ergonomics is a discipline that involves the systematic application of principles, methods, and data from various fields of study to create systems that are optimized for human use. The goal is to ensure that people play a significant role in the design process, resulting in systems that are safe, efficient, and comfortable to use. There exist several studies dealing with workstation improvement. The study[23] aimed to evaluate the physical strain and discomfort caused by different working heights and horizontal distances. It was also focused on to alleviate these issues. To achieve these goals, the researchers examined both physiological and subjective measures of exertion in participants under simulated laboratory conditions. Another study[24] focusing on the inadequate design of traditional gemstone polishing workstations resulting in discomfort and musculoskeletal issues for gemstone polishers due to their constrained working positions. In this study the impact of three workstation adjustment parameters - workstation illumination, polishing height, and tool post position - on postural angle, muscle activity, and perceived discomfort is examined. The study[25] was conducted to enhance the silk degumming and dyeing workstation in the silk weaving industry to alleviate muscle pain experienced by workers. Anthropometric measurements were taken from 400 workers who engage in standing work during silk degumming and dyeing processes. The data obtained was utilized to improve the equipment used. Another study[26] was aimed to analyse the working posture and re-design the assembly workstations in assembly process to improve productivity. The study[27] suggest that implementing a retrofitted squeegee intervention can effectively enhance ergonomic posture, reduce musculoskeletal disorders among High-Speed Performance workers (HSP), and lead to a significant increase in productivity within the textile industry. Numbers of studies are carried out for bringing ergonomic improvements.[28–31] In all the quoted sample studies above, there exists no systematic methodology for workstation improvement. Hierarchy or priority of improvement between the factors was not considered.

The workstation improvement framework based on interpretive structural modelling[13] serves as the foundation for improving workstation in hierarchical manner considering constraint on cost if any. To demonstrate the implementation of the functioning of the workstation improvement framework, the valve lapping task was selected. In India, the valve lapping task is usually performed manually with hand-operated tools/devices which involve a greater number of repetitive actions in an awkward posture which called for its selection. There were other concerns associated as well like unhappy workers leading to unproductive activities like frequent breaks. The complete task was filmed for number of cycles for different operators for posture analysis. Nordic Musculoskeletal Questionnaire (NMQ) was filled by the workers. The fundamental causes of MSD were discovered during an ergonomic assessment of the current method of cylinder head lapping activity. The lapping operator found working in an uncomfortable position for 5–6 hours each day without taking proper breaks. Musculoskeletal issues can result from working in these positions for long periods of time. After thoughtful discussions with workers and supervisors, few prominent factors like posture, working height, work area, arrangement of tools/devices are considered to be taken care of systematically in the new workstation to be designed. Existing postures were analysed with RULA technique in CATIA v5 software. By considering the anthropometry of 50% percentile people, a suitable working height, required area, seat height was finalized. The new workstation is designed by work layout planning, proper arrangement of tools and materials required for the process considering comfortable work envelop. The postures involved in the proposed workstation was again analysed by RULA technique in CATIA v5 software to know about the improvement and the ergonomic work postures are suggested. The data in Table 4 shows the comparison of RULA scores in existing and proposed work settings. The improvement in the RULA score is evident from the values. The average RULA score in an existing work setting is 5.5, which is improved to 3.25 in the proposed workstation.

The approach based on ISM methodology has the tremendous potential for improving workstations by offering a systematic methodology. In this paper, authors first attempted to implement this approach which is proved to be a great way of improving workstation for cylinder head Manual lapping activity. Doing improvements in phase wise manner, there is no chance of missing any important factor. Hence this approach may be implemented in many other industries like paint/art industries, electronic manufacturing industries, hospitals, computer workstations etc. for workstation design and improvement.

Conclusions

With the aid of several industrial engineering technologies, Indian firms are taking proactive measures to increase productivity. Existing workstations' ergonomic analyses and changes considering factors like anthropometry, reach envelop analysis, modification costs, and technology limitations might result in some workable alternatives. In this study, the new layout is recommended following the implementation of the workstation improvement framework to lower the risk of MSDs, and the RULA test run in the CATIA software for the proposed layout can attest to this reduction. The predicted average RULA score for the proposed workstation is 3.25, which is much lower than the estimated average RULA score of 5.5 for the current workstation. The workstation improvement framework is therefore beneficial for creating ergonomic workstations in a systematic manner. In future this study can be extended for the all the factors mentioned in the improvement framework. It can also be applied in different areas.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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