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Course Number	IND712
Course Title	Industrial Ergonomics
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Project Final Report

Assignment Title	Project Final Report
Submission Date	April 7th, 2023
Due Date	April 7th, 2023

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Abstract

The objective of this project is to improve the workplace of a tire replacement shop called "Mr. Used Tire" by focusing on employee well-being and operational performance. Our team aims to address the physical and psychosocial aspects of the workers, including pain, fatigue, and work-related injuries while improving their motivational level. The DMAIC cycle process is to be utilized for improvements and redesign purposes with a focus on enhancing efficiency and overall prosperity of the workplace. To analyze and determine the physical loading and potential injury risks for the workers, the assessment tools to be used are RULA and 4D Watbak. The desired impact of the report on the store is enhanced user experience/satisfaction, increased productivity, an employee-centered workplace design approach, and greater accessibility. The implementation of the suggestions from the report could potentially place a higher priority on worker safety and well-being while reducing absenteeism, and turnover rates and increasing job satisfaction and productivity.

The focus of this report is to examine the work environment of the shop and its aspects that have an impact on employee well-being and operational performance. In order to achieve the best results in the industrial ergonomics analysis of the workplace, our team intends to prioritize the components that have a direct influence on the well-being and productivity of the workers. The components may encompass factors that include the physical work location, day-to-day tasks, equipment used, and quality of managerial guidance. The primary means of data collection procedure is through observational studies, however, interviews are to be conducted with the workers and managers to gather the information that can support further analysis.

Upon the first inspection of the site, the workplace was found to be heavily physical labor centric. The shop primarily focuses on fixing faulty tires or replacing them with new ones. With the exception of tasks that require the use of a two-post lift, wheel balancing machine, tire changers, or automatic torque wrench, all tasks are performed manually. The workers have to manually detach the tires from the vehicles with the help of a hammer before rolling them to the appropriate machines for further action. The physical tasks involve repetitions of bending over, squatting down, lifting, rolling tires, and so on. Performing these manual tasks with awkward postures and heavy lifting can lead to fatigue, discomfort, and the potential risk of work-related musculoskeletal disorders (WMSD). According to a study done by the National Institute for Occupational Safety and Health (NIOSH), the average weight of a passenger vehicle tire is about 20-25 kg [1]. Moreover, manually lifting and moving heavy tires on a daily basis can increase the potential risk of injuries related to MSDs.

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Methods

System Identification

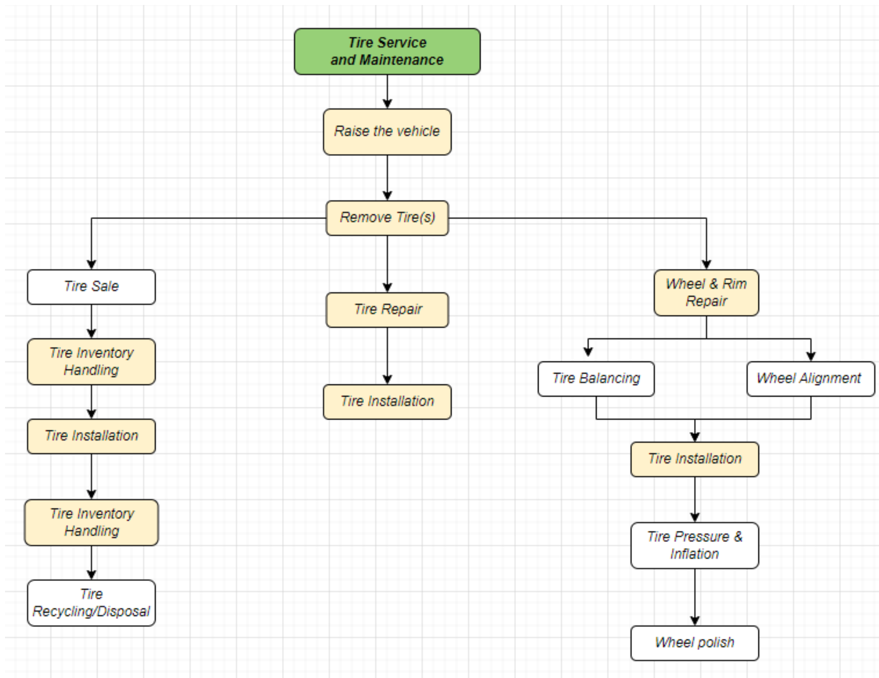

Figure 1: *Hierarchical Task Analysis of Mr.Tire Ltd.*

The Hierarchical task analysis for the system of operations in place at Mr.Tire visually represents the tasks related to the daily operations of the shop floor. Through Hierarchical task analysis, it was determined that the main areas of concern were related to the tire removal, installation, tire inspection, manual lifting of tires, and inventory handling that frequently occur on the shop floor. The subtask components of the manual handling jobs will be closely investigated closely to determine the postures and the biomechanical loads used during the job.

Looking at the Hierarchical Task Analysis figure, it can be seen that the tire removal and installation element are part of all the available services this store is able to provide. In this task, there are elements that require the employee to grab, lift and move the wheel to the work area. The other element in the tire installation and removal process is the tightening or loosening of the bolts. Given that the average weight of a tire with a rim in place is 20-25 kg, the Rapid Upper Limb Assessment (RULA) checklist is used to evaluate the risk of musculoskeletal disorders associated with upper limb work elements. In addition, since the tires and tools are often lifted off the shop floor, a Watbak assessment is performed to analyze the biomechanical loads related to the tasks performed. The tire installation process is the most prominent throughout the entire 8-hour shift and contains precise and accurate movements, which requires the employee's very careful when handling and maintaining the tire.

To remove the tires from the vehicles, they are lifted around 40 cm above the ground. The workers usually bend over or kneel down to remove the lug nuts using an automatic torque wrench. After removing the nuts, the process of detaching the tires from the car is completely hand-operated. If there is resistance to extraction, they would sometimes use a hammer to drive the wheels out of the axle of the car since it can be difficult to tug it out while bending over or kneeling down.

In order to perform an inspection on the customer's tire, the employee must remove the tire from the lifted vehicle and work on the damaged tire on the shop floor. After the removal of the tire, the employee must inspect the tire and grab the necessary tools to repair the customer's request. The workers usually place the tire between their legs and bend over in an awkward position to inspect, as can be seen in Figure 2. Our team was informed that there was no workstation available in the shop where the employees could place the tire for further examination of the faulty tire. From observing the worker inspect the tire, it was clear that the task can be detrimental to the upper back resulting in extreme interval loading onto the spine. This demanded an immediate investigation with the RULA tool.

The other work element in question is the manual handling and transportation of the tire to and from the work site, shown in Figure 4. After conducting an observational study it was discovered that the employees do not carry the tires by hand but rather roll them along the shop floor to the desired location. Each employee must roll a full set of tires for every customer that comes in for a fresh set of tires. Throughout the entire transportation process, the employee is arching his back, engaging unnecessary back muscles, and rolling the tire through the garage multiple times throughout the 8-hour shift. Using 4D Watbak analysis, it was possible to determine the biomechanical loads endured during the transportation process and explore feasible redesign options.

In summary, these tasks constitute the majority of the workflow on the shop floor and they must be closely analyzed to optimize the task performance and reduce the physical and psychological strain. In order to figure out the associated risk from the tasks listed above, the physical loading is going to be analyzed based on posture, force, and time.

Data Collection

To perform a risk assessment for musculoskeletal disorders, questionnaires were handed out and interviews were taken on the shop floor. The recorded images of employees performing their jobs were used to model their postures on 4D-Watbak software. In addition, the RULA checklist will be used to determine the loads during lift or reach tasks. Interviews with employees were carried out to get an in-depth analysis of the physical, psychological, and physiological well-being of the workers.

Employee Well-being

Long-term exposure to static lifting loads can cause musculoskeletal disorders, reduced mobility, cardiovascular disease, chronic fatigue, and reduced grip [2]. In the case of *Mr. Tire,* their employees are manually handling tires throughout their 8-hour shift and the long-term effects are detrimental to the physical and psychological well-being of the team. Even with proper protective equipment and gear worn by employees, prolonged exposure can lead to poorer job performance, quality, and efficiency.

The physiological and psychological states of the employees are crucially important as it is the driving force behind their attitude, motivation, and effort toward their jobs. With a lack of support from management, employees feel less valued and therefore may lead to emotional or physical stress and workplace conflicts. The lack of managerial support programs for employees may lead to higher absence and turnover rates. The NASA Task Load Index survey[3] was used to assess the various demands placed on the workers. In addition, a subset of questions from the COPSOQ questionnaire [4], spanning multiple scales, were administered during the interview process to gauge the psychosocial and cognitive well-being of the employees. The responses have been documented in the Appendix. Through prolonged observations of the employees and informal discussions regarding their work routines, the most recurring postures assumed by the employees were identified. These postures were then analyzed using the RULA, Snook, and Watbak tools to ascertain the biomechanical loads experienced by the workers and their potential long-term impact on performance.

Evaluation Results

Rapid Upper Limb Assessment (RULA) is an ergonomic evaluation tool that can assess the risk of MSDs related to repetitive upper body tasks. The recurring tasks on the job floor are tire inspections and tire installation, figure 2 and 3 show the two tasks in question. As seen in figure 2 and 3, the tasks activate the neck muscles, shoulders, arms, and upper back while performing the tasks

Table 1: RULA Score Evaluation

Final score	Score Interpretation
1 or 2	Acceptable
3 or 4	Investigate further
5 or 6	Investigate further and change soon
7	Investigate and change soon

After evaluating the posture utilizing the RULA tool, the final score obtained was *7*, indicating the immediate need for investigation and alterations. The assessment can be found in the Appendix in Figure 8. The high score represents the associated musculoskeletal risks from certain types of tasks. This demonstrates a higher chance of MSDs which eventually decreases productivity as the workers experience pain and discomfort. Moreover, MSDs can increase healthcare costs while reducing the quality of life and job satisfaction. Workers experiencing extreme fatigue, pain, and discomfort are most likely to be absent, less productive, and leave their job. Absenteeism, worker productivity, and the turnover rate can be immensely detrimental to the store in terms of cost and the revenue it generates.

A final score of 7 was obtained after assessing the task presented in Figure 3 using the Rapid Upper Limb Assessment tool. The upper neck, back, and arm positions and the engaged posture are the leading factors toward a score of 7 for the tire removal task. From A: The engaged upper arm position for this work element was about 45 degrees (+2) with a lower arm position of 90 degrees (+2). The wrists are angled 10 degrees inwards (+2), twisted in the mid-range of motion, and a load of 17 kgs is pulled (+3). From B: The neck is facing 10 degrees downwards (+2), the trunk position is 45 degrees (+3), legs are supported (+1). These RULA elements contribute to a final Table C score of 7. The engaged upper body posture, limb positions, and weight of the tire signify the task or work element must be redesigned for the long-term health and safety of the employee.

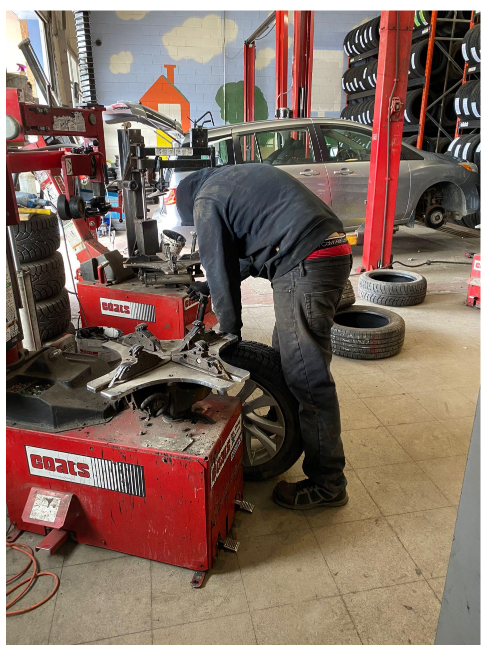

Figure 2: Image of *Mr. Tire* employee inspecting tire

Figure 3: Image of *Mr. Tire* employee removing the tire from vehicle

Figure 4: Image of *Mr. Tire* employee rolling the tire to the work site

Using figure 4 to model a digital simulation of the task in 4D-Watbak software. Taking into consideration the employee's age, sex, weight, height, and any additional loads, Watbak is able to simulate the biomechanical loads, stress, and moments engaged throughout the simulated work element. After simulating the task from Figure 4, the following results of the original design were obtained:

User: 95th percentile male **;** ***Load***: 17 kg

Table 2: Watbak software results of original task design

L4-L5 Moment	*L4-L5 Compression*	*Reaction Shear*	*Joint Shear*	*R shoulder flexor/extensor*	*L shoulder flexor/extensor*
223.9 Nm	4113 N	402 N	1242 N	83.4 N	83.4 N

User: 50th percentile male **;** ***Load***: 17 kg

Table 3: Watbak software results of original task design

L4-L5 Moment	*L4-L5 Compression*	*Reaction Shear*	*Joint Shear*	*R shoulder flexor/extensor*	*L shoulder flexor/extensor*
166.6 Nm	3102 N	289 N	913 N	83.4 N	83.4 N

The software results show that the spine compression and spine joint shear both exceed the allowable limits. For the 95th percentile male, the spine compression is 1321 N above the NIOSH allowable limit and the spine joint shear is 1242 N which exceeds the 500 N UW allowable limit and the UW maximum possible limit. For the 50th percentile male, the spine compression is only 313 N below the NIOSH allowable limit and the spine joint shear is 913 N which exceeds the 500 N UW allowable limit and is 87 N below the UW maximum possible limit. The spine compression and joint shear require a redesign to remain below the limits and reduce the strain from repetitive motions. The results demonstrate that all employees are at risk of developing musculoskeletal disorders.

Design Improvements and Recommendations

Biomechanical load Improvements

Using the 13 Design Principles and Reason's Error Model to model our design improvements and recommendations, the main objective was to reduce the physical strain and biomechanical loads of the employee's experience and improve the quality of operations.

A workstation table for the employees to place the tire after detaching them is highly encouraged. The task and workstation should be designed in such a way that enables the workers to perform their duties in the most natural and neutral position possible, minimizing strain and distress. The least amount of loading is believed to be present in a neutral posture when the body is at ease, and proportionate, and the arms are near the torso. Usually, the poorer the working posture is, the higher the RULA score will be since the body deviates from the neutral standing position. As suggested in Figure 3, workers' standing posture should be as neutral as possible with shoulders relaxed, elbow bent at a 90-degree angle, forearms parallel to the floor, neck, and spine aligned, and their feet shoulder-width apart. With the help of an adjustable workstation, the workers can comfortably perform their inspection on the tires with a natural posture. A RULA assessment was performed again with the recommended posture (Figure 5). This time the final score went down to 3 indicating a much lower risk of pain and fatigue in the upper body. For the sake of the redesigned assessment, the posture considered for the workstation is much more relaxed and the workers are in control of their movements. Factors that had the most impact on the new score are neck, trunk, arm and leg position, and wrist analysis. For the proposed workstation, the tire is on the table with an adjusted height based on workplace height design guidelines (Figure 3) which provides less physical loading on the worker's body. A score of 3 still indicates further investigation due to the fact that the task is physically demanding and the heavy weight of the tire still has an impact on the final score. Additionally, The workstation is suggested to be adjustable so that the design includes as many people as possible.

The current car lift in place can be seen to lift the vehicle to a vertical height of about 40 centimeters above the ground. The RULA assessment for the removal of a tire showed a final score of 7, this work element was investigated further to determine the root cause of such a poor score. One major concern with the evaluation of the employee's jobs was the vertical height at which employees were manually loading and unloading a tire from the wheelbase of the vehicle. The engaged posture during this work element can be seen to be unsafe, this is due to the vertical lifting limit of the current car lift. To mitigate this problem a new car lift is proposed, the BENDPAK vertical car lift 10AP model [5] allows the operator to raise vehicles weighing up to 4536 kilograms to a maximum height of 2.1 meters. Given that the ceiling height in the *Mr. Tire* garage is 10 meters, the suggested car lift is a suitable size for the shop floor. With the recommendation in place, if the vehicle were raised to a vertical height of 1 meter then the operator would not have to arch his back and engage in an uncomfortable posture as seen in Figure 3. The operator would now be able to stand upright and remove the tire while only using his shoulders, arms, and wrists. After performing a Rapid Upper Limb Assessment with the new vertical height, the determined score for this job element was 2. It can be concluded that raising the vehicle to a height of 1 meter would improve the ergonomics behind this task element.

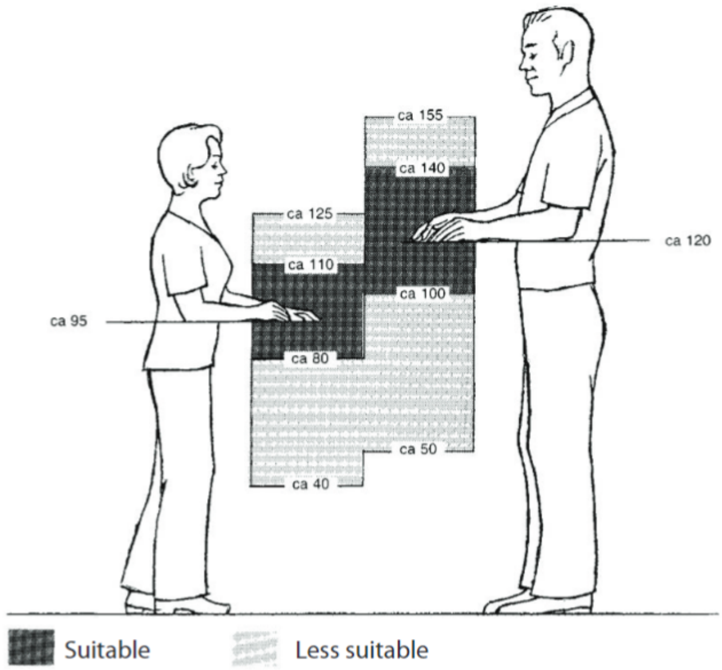

Figure 5: Workplace height design guideline [2]

Table 4: RULA score comparison

	Current system	Proposed system
Tire inspection	7	3
Tire removal	7	2

Note: Refer to Table 1 for score evaluation

Operational Improvements

The addition of a rolling tire rack will substantially aid the employees during their manual handling process of tires, the rack can hold up to 8 tires and is easily maneuverable around the garage floor. The employee will now be able to safely transport a set of tires to their desired location safely and efficiently without having negative impacts on the user's back. With the implementation of the rolling tire rack, maneuverability will effectively reduce the stress on posture, requiring less strength and compression [6]. However, this new equipment in the store brings a new set of risks and requirements. The shop floor must be free of tools and any other objects that may obstruct the tire rack to avoid any unexpected collisions. The rack will require some grip strength, and the stress and strain on the hands may require continuous monitoring and improvement.

User: 95th percentile male **;** ***Load***: 17 kg

Table 5: Watbak software results of redesigned task

L4-L5 Moment	*L4-L5 Compression*	*Reaction Shear*	*Joint Shear*	*R shoulder flexor/extensor*	*L shoulder flexor/extensor*
90.3 Nm	2059 N	14 N	353 N	83.4 N	83.4 N

User: 50th percentile male **;** ***Load***: 17 kg

Table 6: Watbak software results of redesigned task

L4-L5 Moment	*L4-L5 Compression*	*Reaction Shear*	*Joint Shear*	*R shoulder flexor/extensor*	*L shoulder flexor/extensor*
67.7 Nm	1563 N	-27 N	227 N	83.4 N	83.4 N

Psychosocial State Improvements

After interviewing the employees, it was found that they did not have much control over the operational procedures. Throughout their shift, they are usually completing the routine of tasks by themselves. The tasks are never divided since each employee gets one car to operate by themselves. Therefore the job does not involve much engagement with other employees. Heavy physical work with little to no human interaction can push towards high stress and low motivation levels. The workers have low control over how they can perform the tasks with very low support and supervision. Poor workstation and equipment design reduces workers' control over tasks and increases psychosocial demands. In order to achieve increased productivity, the work environment design should be user-centered. To address the psychosocial factors affecting the employees, the store stakeholders should create a positive work environment through the right levels of task control, demands, and administrative support. Valuable leadership can lower negative stress and raise positive stress. When there is a lack of support from superiors and also from the work environment, the workers face higher levels of struggle while completing their tasks which results in negative stress. Negative stress can lower motivation which as a result lowers productivity. Physically demanding jobs with little support increase negative stress which brings in potential risks of long-term symptoms of chronic stress such as poor health, anxiety, exhaustion, high blood pressure and reduced capability to recover. On the other hand, positive stress is known as a temporary adrenaline kick that takes place when people are in a challenging situation but are confident in their ability and circumstances that they can complete the job successfully. Positive stress can help intensify alertness and motivation which can boost productivity.

Cost of Improvements

Mr. Tyre has 8 employees and 1 manager overlooking the daily operations of the shop, currently, there are 2 vertical car lifts and 2 car jacks in store. The proposed recommendation is that the vertical car lifts be replaced with the BENDPAK model to improve the work environment. Additionally, hiring additional personnel, and providing proper training and support resources must be considered.

The cost calculation of the proposed redesign solution:

Table 7: Cost of Improvements

Equipment	Quantity (Units)	Price ($)	Total Cost ($)
BENDPAK Vertical Car Lift	2	4980	2 x 4980 = 9960
Rolling Tire Rack	3	120	3 x 120 = 360
Adjustable Work Table	3	173	3 x 173 = 519

Upon our approach for the project, the shop manager informed us that the recommendations of this report would be considered, as long as it does not come at any cost to the shop. However, the analysis of the report suggests major alterations to the workplace and implementations of equipment would benefit the shop and its employees.

Discussion and Conclusions

The report is composed based on the study of ergonomics and human factors design consideration. The recommendations and design improvements are determined by a thorough analysis of the workstations and workflow utilizing research-based ergonomic tools such as 4-D Watbak software and RULA, along with interviews and questionnaires. With the help of these tools, it was possible to critically analyze the employees' postures, and biomechanical loads and redesign the job elements to be below the maximum acceptable weight limits and therefore reduce potential risks related to MSDs. The 4D-Watbak analysis shows that the posture used through the original design of the task puts the employee at risk of developing MSDs. The analysis results of the implementation of the rolling tire rack, adjustable work table and vertical car lift show significantly reduced biomechanical loads. The spinal loading forces, moments, and compressions of the back magnitudes are severely reduced with the use of all recommended equipment. If the recommended improvements are considered by the shop, they could increase the rate of operations, and efficiency, while also addressing worker safety and satisfaction in the workplace.

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Appendix

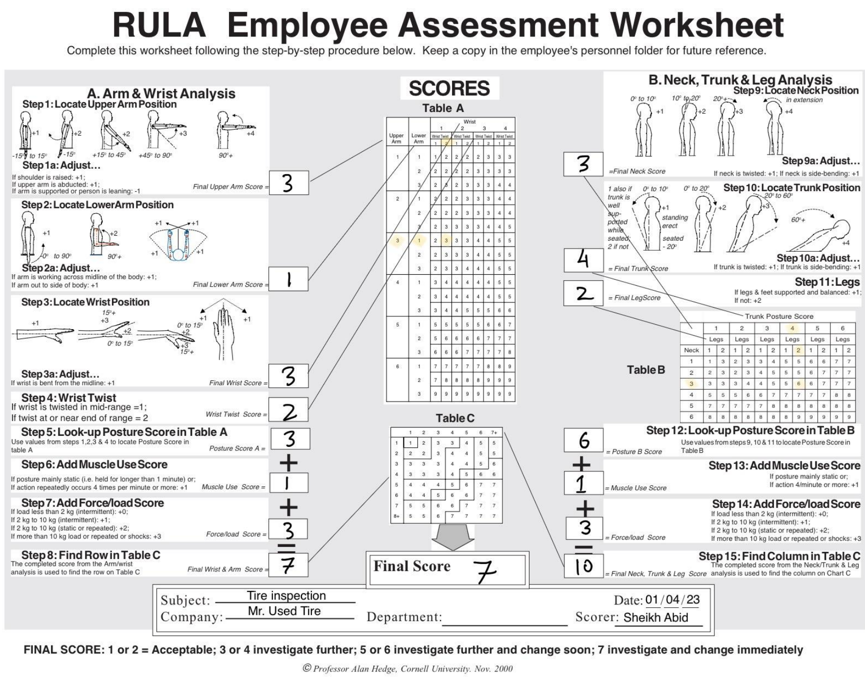

Figure 6: RULA assessment of tire inspection

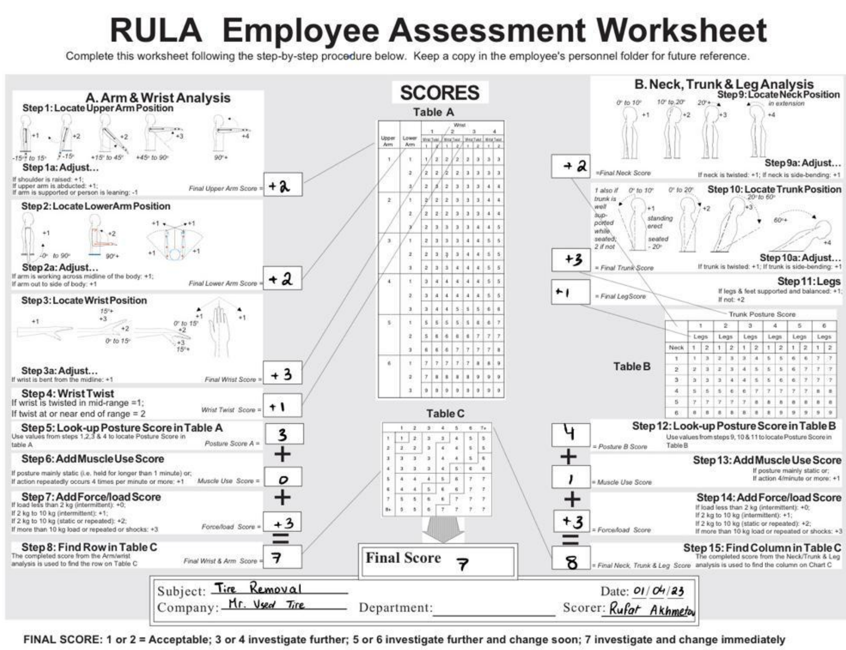

Figure 7: RULA assessment of tire removal

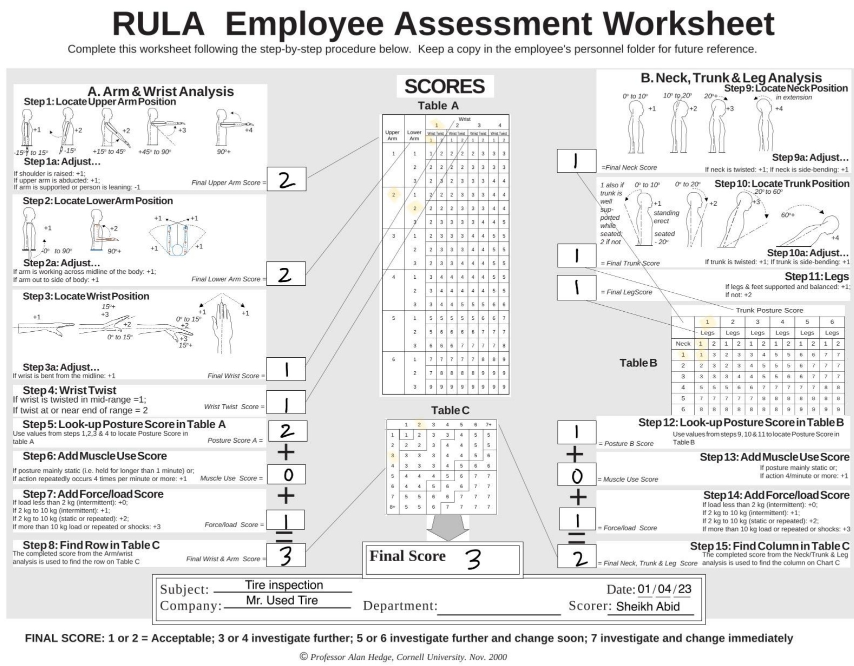

Figure 8: RULA assessment of proposed tire inspection

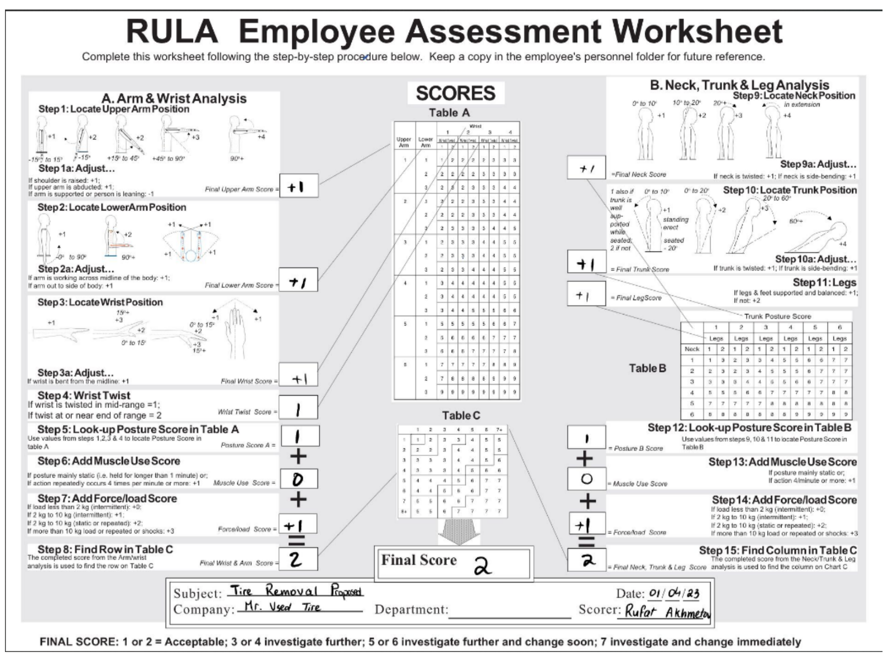

Figure 9: RULA assessment of proposed tire removal

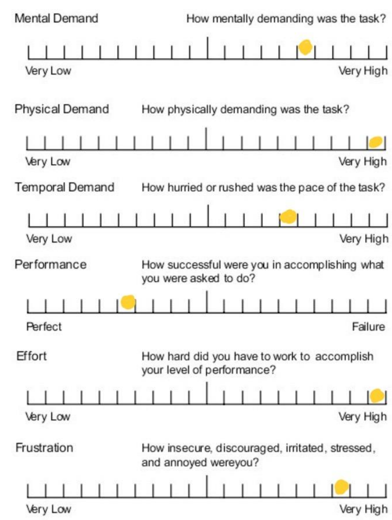

Figure 10: NASA Task Load index survey for Tire replacements

Figure 11: Rolling Tire Rack

Figure 12: Adjustable Work Table

Figure 13: BENDPAK vertical car lift

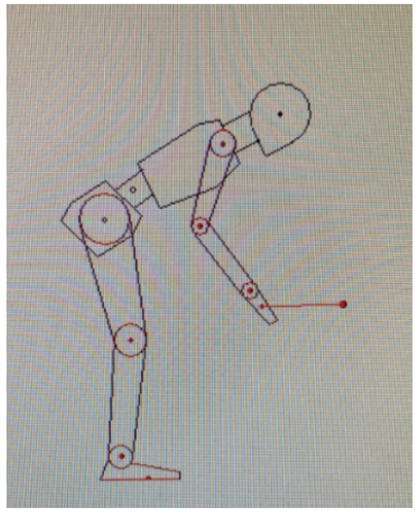

Figure 14: 4D Watbak modeling of manual tire handling

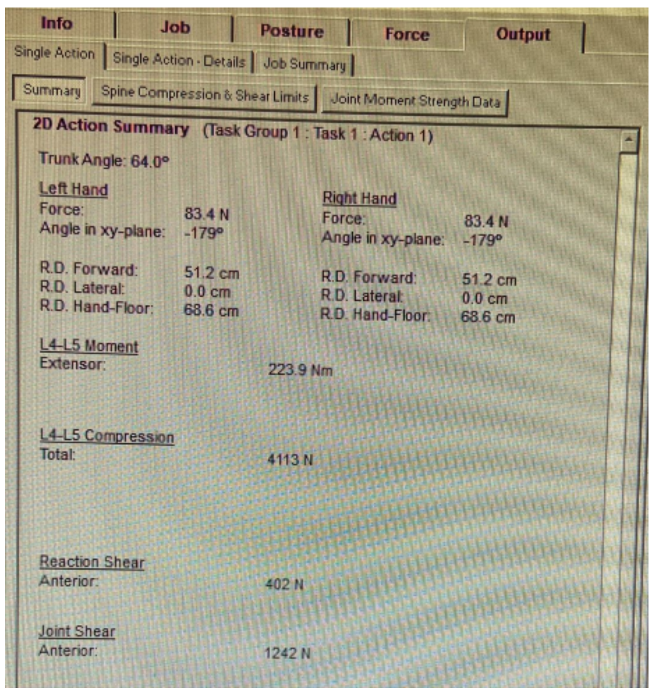

Figure 15: 4D Watbak analysis results for 95th percentile male

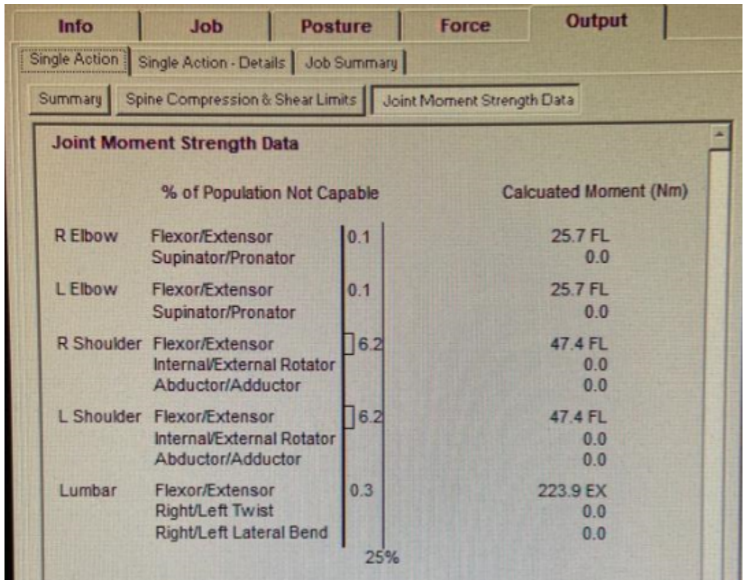

Figure 16: 4D Watbak analysis for 95th percentile male Joint Moment Strength Data

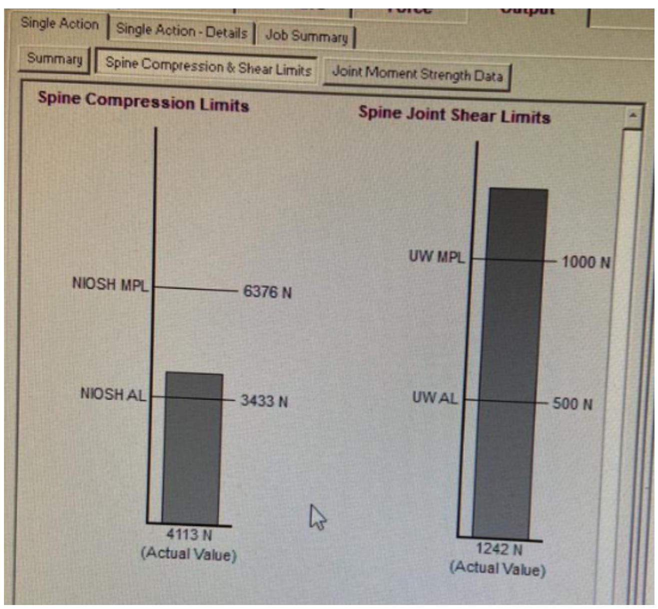

Figure 17: Spine compression and Shear limits for 95th percentile male

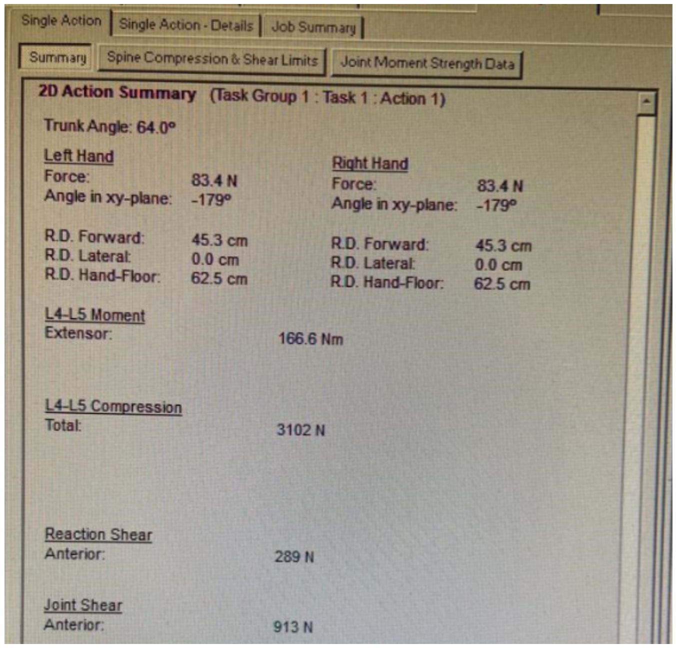

Figure 18: 4D Watbak analysis results for 50th percentile male

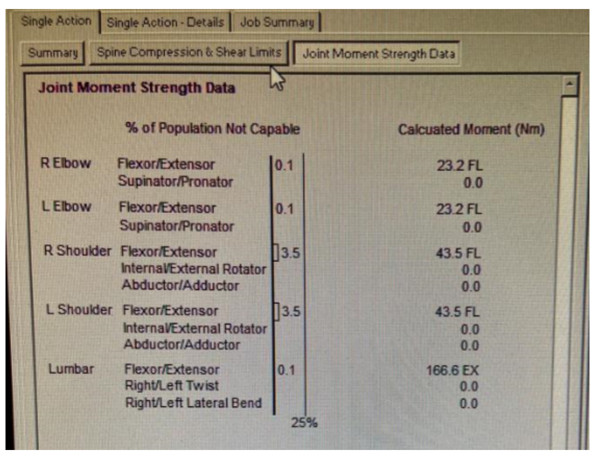

Figure 19: 4D Watbak analysis for 50th percentile male Joint Moment Strength Data

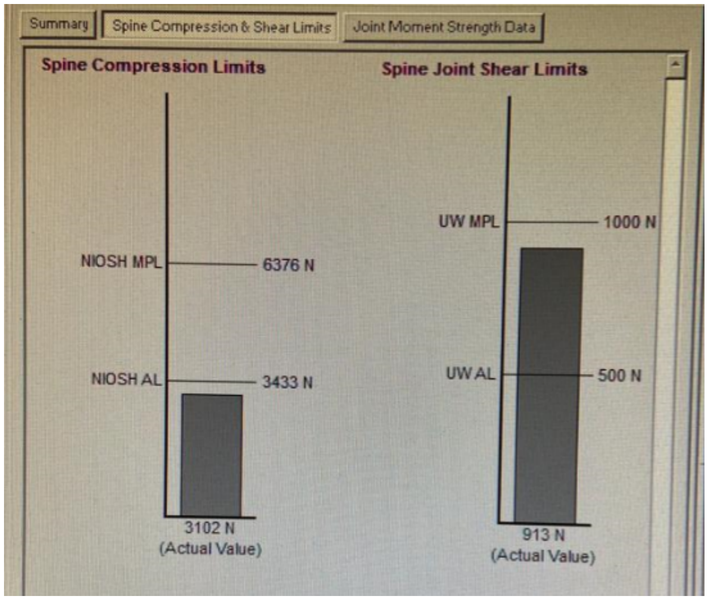

Figure 20: Spine compression and Shear limits for 50th percentile male

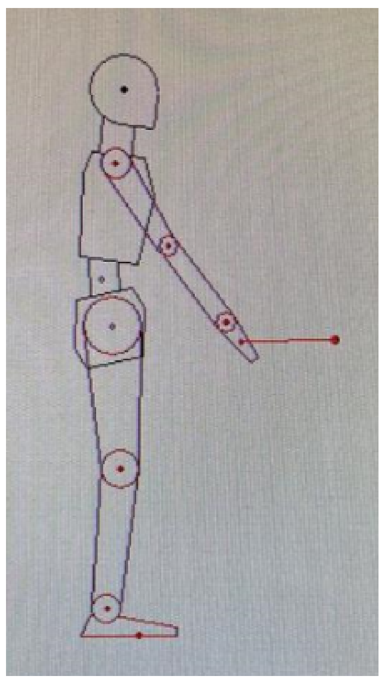

Figure 21: Posture during pushing tire rack

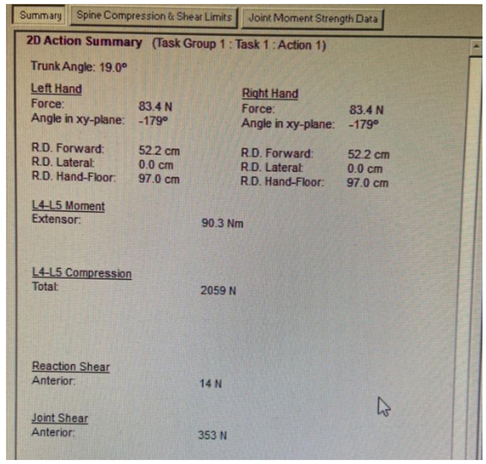

Figure 22: 4D Watbak analysis results for 95th percentile male

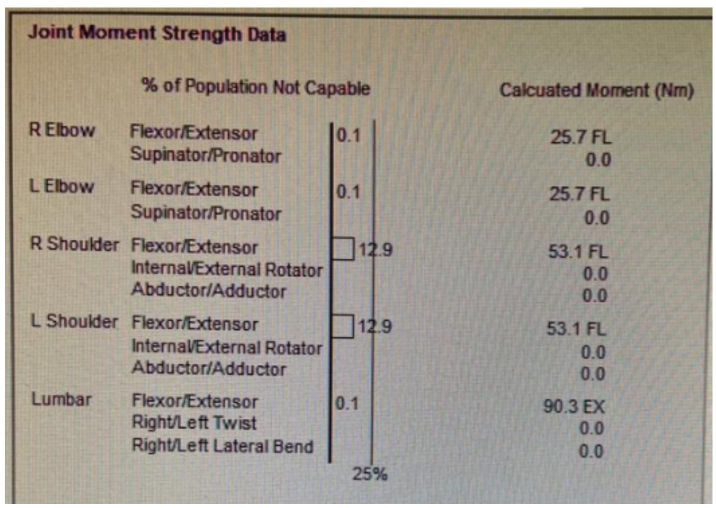

Figure 23: 4D Watbak analysis for 95th percentile male Joint Moment Strength Data

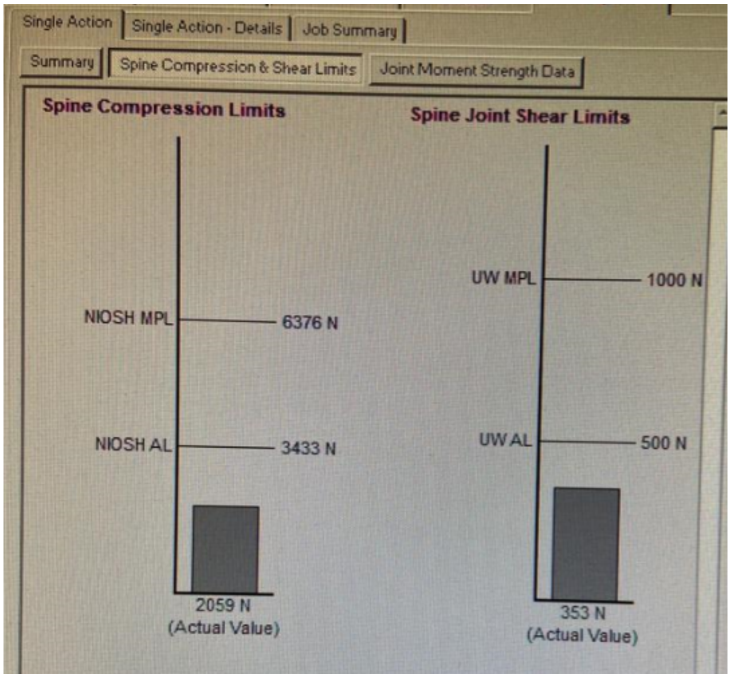

Figure 24: Spine compression and Shear limits for 95th percentile male

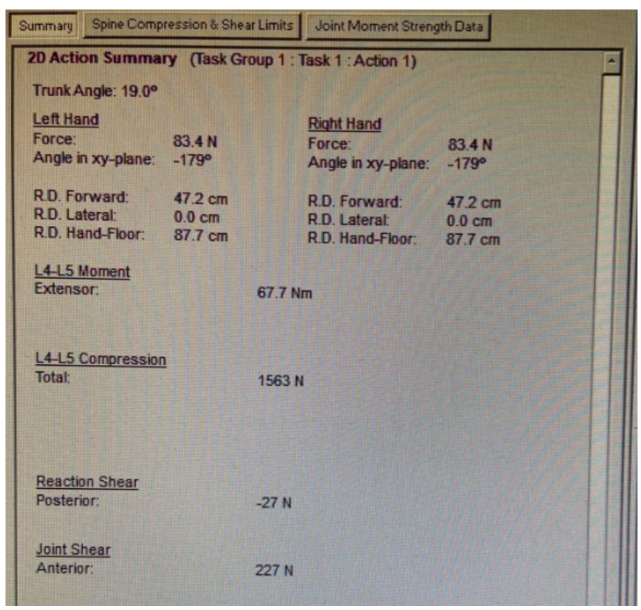

Figure 25: 4D Watbak analysis results for 50th percentile male

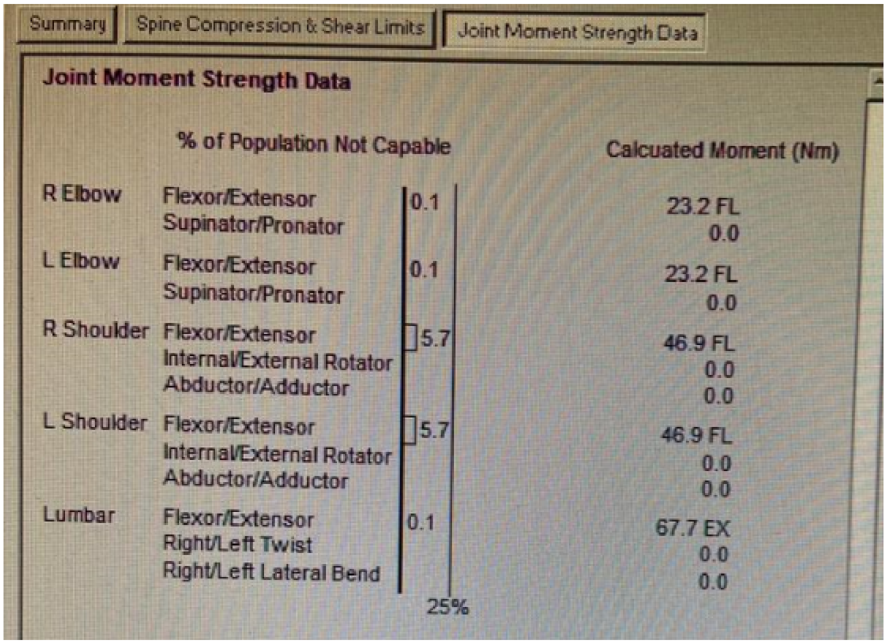

Figure 26: 4D Watbak analysis for 50th percentile male Joint Moment Strength Data

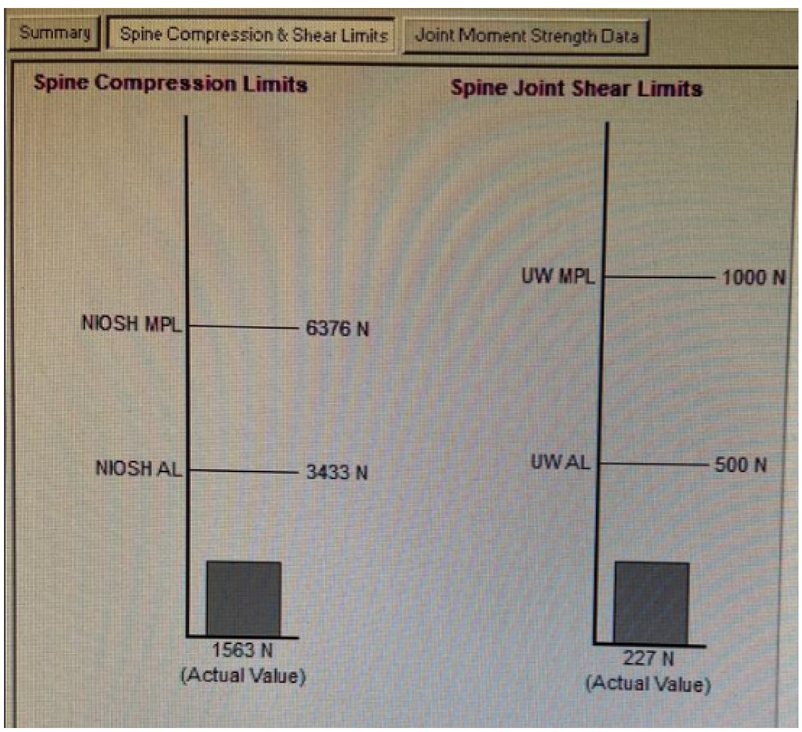

Figure 27: Spine compression and Shear limits for 50th percentile male

Questionnaires

Worker Interview

- **What aspects of the job do you dislike?**
  The job is very physical and we have to use a lot of force to get the job done. There is not enough equipment for all the work which makes the job a lot tougher.

- **What would you change about the job/workplace and why?**
  Add more machines that can help us do our job faster and easier.

- **Any discomfort while working if so where?**
  Shoulder and neck pain

General Health

- In general, would you say your health is: (Excellent/Very Good/**Good**/Fair/Poor)

- I expect my health to get worse (Definitely true/Mostly True**/Don't Know**, Mostly False, Definitely False)

- My health is excellent (Definitely true/**Mostly True**/Don't Know, Mostly False, Definitely False)

- I am as healthy as anybody I know (Definitely true/**Mostly True**/Don't Know, Mostly False, Definitely False)

Somatic Stress

- Been short of breath? (Always, Often, **Sometimes**, Seldom, Never)

- Had tension in various muscles? (Always, Often, **Sometimes**, Seldom, Never)

- Had a tendency to sweat? (Always, **Often**, Sometimes, Seldom, Never)

- Had tight chest or chest pains? (Always, Often, Sometimes, **Seldom**, Never)

Cognitive Stress

- Had problems concentrating? (Always, Often, Sometimes, **Seldom**, Never)
- Had difficulty in taking decisions? (Always, Often, **Sometimes**, Seldom, Never)
- Had difficulty in remembering? (Always, Often, Sometimes, **Seldom**, Never)
- Found it difficult to think clearly? (Always, Often, Sometimes, Seldom, **Never**)