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Ergo-mechanical Approach of Designing Truck Tire Installation Tool for Small Workshops

I Gede Bawa Susana, I Gusti Agung Ketut Chatur Adhi Wirya Aryadi, Hafiz Jefry
Department of Mechanical Engineering, Faculty of Engineering, University of Mataram, Mataram, Indonesia

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ABSTRACT

Manual truck tire installation can cause musculoskeletal disorders due to unnatural postures and high physical demands. This study aims to assess the prevalence of musculoskeletal complaints among truck tire installation workers and to design a truck tire installation aid based on an ergo-mechanical approach. The level of musculoskeletal complaints was measured using the Nordic Body Map questionnaire with a four-point Likert scale in five workers, before and after work. The measurement results showed an average musculoskeletal complaint score of 54.2 after work, placing it in the moderate-risk category and requiring corrective action. Based on these findings, a truck tire installation aid was designed using worker anthropometric data, employing a 5th-percentile approach to ensure the safety and comfort of workers with small body sizes. The body dimensions used include standing elbow height, palm length, knee height, foot length, and horizontal standing reach. The results of translating anthropometric data into technical designs indicate that the proposed assistive device has the potential to improve work posture, reduce physical load, and lower the risk of musculoskeletal disorders. Although this research remains limited to the conceptual design stage and lacks prototype testing, the results can serve as a basis for developing and evaluating ergonomic assistive devices in real work environments.

Corresponding Author:

I Gede Bawa Susana
Department of Mechanical Engineering, Faculty of Engineering, University of Mataram
Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125, Indonesia
Email: gedebawa@unram.ac.id

INTRODUCTION

Truck tire installation activities in workshops, especially on a small scale, are still carried out manually, especially in the process of lifting, aligning, and inserting tires onto the rim axle, mainly on trucks with six wheels. Truck tires have considerable weight and diameter, so workers often must work in a bent position, twisting their bodies, and applying pushing and lifting forces that exceed safe work limits. This is an unnatural working posture. It can cause physical fatigue, increased workload, and a higher risk of musculoskeletal injuries, including lower back pain, shoulder strain, and wrist injuries.

Increased risk of occupational injuries caused by musculoskeletal disorders and exposure resulting from unnatural and unusual working postures (Bridger, 2003; OSHA, 2025a). Furthermore, installation time can increase due to the difficulty of precisely controlling tire position by hand. Applying ergonomics principles to work tool design is essential to minimize these risks. One commonly used approach is the integration of ergonomics and mechanics (ergo-mechanical).

The ergo-mechanical approach is the design of mechanical systems that account for human body limitations. The ergo-mechanical approach can be used to address work issues related to occupational health and safety, work tools, and ergonomics (Suarjana et al., 2022). Research by Susana et al. (2024a) indicates that ergo-mechanical applications will produce work tools that are comfortable for workers to use and meet engineering specifications, as evidenced by the work tools' technical characteristics. Ergo-mechanical is a system for studying the ergonomic synergy between workers and mechanical systems of work tools to increase workforce productivity and efficiency, as well as ergonomic mechanical structures that are easy to use across various applications (Adnyana et al., 2015; Yong et al., 2019). The ergo-mechanical approach improves work comfort, thereby increasing worker productivity and quality of life (Susana et al., 2024b). Reduced unnecessary movements and physical demands, decreased injury rates and workers' compensation costs in the production process as a result of modifying work equipment with ergonomic interventions (OSHA, 2025b). Many workers still perform manual handling in production processes due to limited funds and knowledge. For example, manual work such as installing truck tires involves unnatural postures. Manual handling is often a crucial part of the workflow, especially in sectors that are not yet fully automated. Manual handling activities pose significant ergonomic risks because they can increase physical strain and lead to musculoskeletal disorders. Rajendran et al. (2021) explain that manual activities such as lifting, lowering, pushing, pulling, and work that generates vibrations have the potential to cause musculoskeletal disorders. This indicates that workers face a high level of ergonomic risk, necessitating the selection of appropriate ergonomic equipment to support risk analysis for each task and the analysis of work postures.

The manual working posture for truck tire installation involves a series of body movements that require physical strength, such as lifting the tire, rotating it for bolt alignment, pushing or pulling it toward the axle, and maintaining the working position with an unbalanced body weight. Based on ergonomics principles, these postures are considered unnatural and high-risk because they involve static and dynamic loading on the musculoskeletal system. Unnatural work postures such as squatting and hunching can lead to musculoskeletal disorders and postural changes, which pose ergonomic risks (Nadila & Suryadi, 2024; Tanjung et al., 2023). Olowogbon et al. (2021) explain that poor work posture due to improper lifting and manual handling in agriculture can lead to musculoskeletal disorders (MSDs) such as pain and soreness in the neck, shoulders, back, upper and lower arms, and ankles. Reducing musculoskeletal disorders (MSDs) can be achieved through broad ergonomic interventions that center on human workers (Benos et al., 2020; Imada, 2000; Burgess-Limerick, 2018). The installation of truck tires, as shown in Figure 1, demonstrates an unnatural working posture that increases the risk of musculoskeletal disorders.

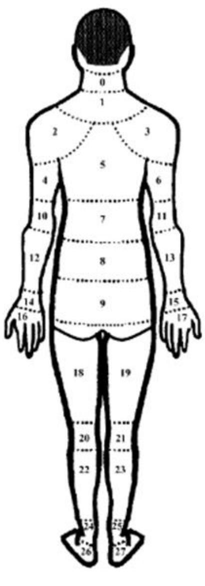
Figure 1. Unnatural Working Posture When Installing Truck Tires

Manually installing truck tires poses significant ergonomic risks and can lead to musculoskeletal disorders if not handled properly. Therefore, studying work posture is an important basis for designing safer and more efficient tire installation tools. In the context of truck tire installation, the tool must adapt to the user's characteristics, including height, arm reach, shoulder width, and elbow height when standing. The use of anthropometric data is essential for optimal tool design that avoids detrimental working postures. Mismatches between anthropometric dimensions and tools or equipment are known to cause discomfort, fatigue, injury, and biomechanical stress in users (Kaewdok et al., 2022). Anthropometry is used as a basis for ergonomic considerations in the design of interactions between workers and work equipment. Anthropometric dimensions serve as important references for designing ergonomic products, equipment, and work environments and can be applied to various design needs, including household facilities (Kaewdok et al., 2020). Individuals have varying body shapes, sizes, and weights. Therefore, anthropometric data is needed to adapt tools to their users to achieve safe, comfortable, healthy, effective, and efficient working conditions (Wignjosoebroto, 2008; Sari et al., 2020). To be applicable to the dimensions of a work tool, anthropometric data are expressed as percentiles. Percentile values indicate the proportion of a population with a given body size and are used to analyze anthropometric data (Wignjosoebroto, 2008; Iridiastadi and Yassierli, 2019). The use of anthropometric data provides a quantitative basis for determining tool dimensions to suit the intended user population.

The ergo-mechanical approach enables tool design to account for the user's capabilities, limitations, and anthropometric characteristics, resulting in a safer, more comfortable, and more efficient work system. This research focuses on the design of a truck tire installation tool based on an ergo-mechanical approach, presented as conceptual engineering drawings, without involving the prototyping stage or performance testing. The novelty of this research lies in integrating pre- and post-work measurements of musculoskeletal complaints, based on the Nordic Body Map, with an ergo-mechanical approach and participatory ergonomics in the design of the truck tire installation tool. In addition, the use of comprehensive anthropometric data based on the 5th percentile of workers is directly translated into the tool's technical specifications, resulting in an inclusive, ergonomic design that reflects workers' real needs. This approach bridges ergonomic risk analysis with the implementation of applicable engineering solutions in the manual work sector. This research produces an initial design model that can be used as a basis for further development towards the stages of structural validation, mechanical simulation, and empirical testing in real work environments. A conceptual design that integrates mechanical requirements and anthropometric-based ergonomic aspects can serve as a reference in developing a safer and more adaptable truck tire installation tool. This design phase is expected to provide an initial foundation for further research focused on prototyping, ergonomic evaluation, and tool effectiveness analysis.

METHOD

The research began with a visit to a small-scale workshop that manually installs truck tires. Observations of the workers' unnatural postures while installing truck tires were conducted, and interviews were conducted, and a Nordic Body Map (NBM) questionnaire was completed. The Nordic Body Map (NBM) is a simple questionnaire used to identify the location and musculoskeletal complaints across the body, as shown in Figure 2.



No	Location	Grade of complaints			
		A	B	C	D
0	Pain/stiff in the upper neck				
1	Pain in the lower neck				
2	Pain in the left shoulder				
3	Pain in the right shoulder				
4	Pain in the left upper arm				
5	Pain in the back				
6	Pain in the right upper arm				
7	Pain in the waist				
8	Pain in the buttock				
9	Pain in the bottom				
10	Pain in the left elbow				
11	Pain in the right elbow				
12	Pain in the left lower arm				
13	Pain in the right lower arm				
14	Pain in the left wrist				
15	Pain in the right wrist				
16	Pain in the left hand				
17	Pain in the right hand				
18	Pain in the left thigh				
19	Pain in the right thigh				
20	Pain in the left knee				
21	Pain in the right knee				
22	Pain in the left calf				
23	Pain in the right calf				
24	Pain in the left ankle				
25	Pain in the right ankle				
26	Pain in the left foot				
27	Pain in the right foot				

Figure 2. Nordic Body Map (NBM)

This questionnaire was used because it is simple and quick, accessible to workers with low levels of education, and visually appealing. This ensures that respondents are not confused, that it is suitable for initial surveys and risk mapping, and that it is easy to process. The total score of the Nordic Body Map (NBM) questionnaire can be used to classify the actions required for the tools used in the work. The Nordic Body Map (NBM) is used to assess ergonomic risk during work activities (Pratama et al., 2024). Next, to design the work tools used, anthropometric measurements, or data on the worker's body dimensions, are taken. Anthropometry is measured in accordance with the work tool design requirements. Only essential body parts are measured. Tools used to measure anthropometric data include anthropometers, segmometers, and rulers (Antropometri Indonesia.org, 2025). The use of anthropometric data allows designers to adjust and refine the dimensions of workspaces and furniture to suit user characteristics (Bridger, 2017). In this study, the anthropometry measured included standing elbow height (D4), knee height (D15), arm length (D28), leg length (D30), and standing horizontal reach as presented in Figure 3 (Antropometri Indonesia.org, 2025).

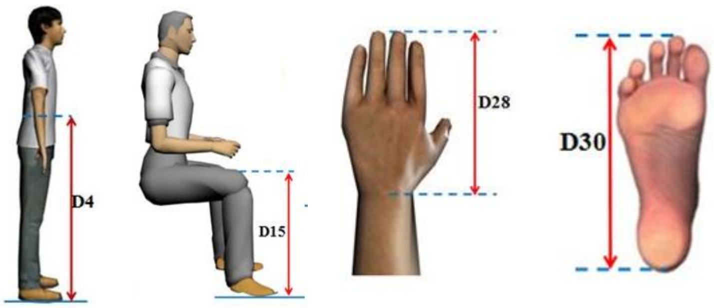


Figure 3. Anthropometric Data for Truck Tire Mounting Tool Design

Standing elbow height in an upright position is used for the tool handle height. Palm length is used for the handle diameter, knee height for the tool lever, foot length for the base length, and standing horizontal reach for the worker's maximum reach length. The worker's anthropometric measurements are first converted to percentiles. The use of percentiles in anthropometric analysis describes the proportion of individuals in a population with a given body size. These percentile values are then used to determine design dimensions. In ergonomic design, percentiles are used to ensure that products, workspaces, and tools are suitable for a large portion of the population (neither too small nor too large). Percentile values for anthropometric data are determined through calculations using statistical parameters in the form of the mean and standard deviation of the respondents' body measurements.

$$P_x = \bar{X} \pm (Z_x \, x \, \sigma) \quad (1)$$

P_x is the xth percentile value, $\bar{X}$ is the average value, Z_x is the normal standard value (score for the xth percentile) based on the table, σ is the standard deviation, and the (+) sign is used for large percentiles and the (–) sign is used for small percentile values. The mean value ($\bar{X}$) is calculated based on Equation (2).

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \quad (2)$$

X_i is the i-th data value, and n is the total number of data (samples used). The standard deviation (σ) is calculated using Equation (3).

$$\sigma = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}} \quad (3)$$

The sample used was five workers who installed truck tires. The sample size was calculated based on the measurement scores for the level of musculoskeletal complaints among workers after work. The sample size was determined using the formulas from Colton (1985) and Ahmed et al. (2017), as shown in Equation (4).

$$n = \left[\frac{(Z_\alpha - Z_\beta)\sigma}{(\mu_1 - \mu_0)}\right]^2 \quad (4)$$

n is the sample size, Z_α is the Z value for type I error = α, Z_β is the Z value for type II error = β, $\mu_1 - \mu_0$ is the average expected change, μ_0 is the average of the research variable without treatment (before improvement), μ_1 is the average of the research variable with treatment (after improvement), σ is the standard deviation, and α is set at 0.05. Type I error is accepted at α = 0.05, and type II error is accepted at β = 0.05.

Dimensions for the design of a truck tire installation tool using the 5th percentile value application. The 5th percentile is used as the minimum body size threshold for the worker population. In the context of truck tire installation workers, the use of the 5th percentile aims to ensure that the tool, workspace, and reach points can be used by workers with even the smallest body size. The research was limited to results in the form of ergonomic designs based on an ergo-mechanical approach, specifically by using anthropometric data from truck tire installation workers. In addition to facilitating the installation of truck tires, it also creates a comfortable work environment. Design involves creating a blueprint or layout for the product to be manufactured. At this stage, measurements of the product's length, diameter, and other dimensions are taken. At this stage, product design is carried out using applications such as Infinite Design, SketchUp, and Autodesk.

RESULTS AND DISCUSSION

Musculoskeletal complaints are subjective symptoms of the musculoskeletal system, assessed using a modified Nordic Body Map questionnaire with four Likert scales. Measurements were taken twice, before starting work and immediately after finishing, each on 5 samples. The assessment criteria with four Likert scales are A = 1, meaning no pain (can carry out work without complaints), B = 2, meaning somewhat pain (can work although sometimes feels pain) and feels little complaints or pain in the skeletal muscles, C = 3, meaning pain (can work although not completely) and the subject feels complaints or pain in the skeletal muscles and often interferes with work, and D = 4, meaning very pain (feels pain and cannot carry out work) and the subject feels complaints or pain in the skeletal muscles and is very disruptive to work. Table 1 presents the levels of musculoskeletal complaints among workers before and after manual tire installation.

Table 1. Musculoskeletal Complaints Data of Workers Before and After Manual Truck Tire Installation

Sample	Before Work	After Work
1	30	51
2	32	55
3	30	54
4	32	57
5	31	54
Average	31	54.2

The musculoskeletal complaint scores, as shown in Table 1, indicate that workers were at low risk before manually installing truck tires. This is evident from the average musculoskeletal complaint score of 31. According to Table 2, a total score of 28-49 falls within the low-risk category (Tarwaka, 2019). After work, workers were at a moderate risk level, as evidenced by the average post-work score of 54.2. This condition requires corrective action on the work tools used by workers when installing truck tires. A musculoskeletal complaint score of 50-70 indicates a moderate risk and requires corrective action, as presented in Table 2 (Tarwaka, 2019).

Table 2. Classification of Musculoskeletal Complaints

Action level	Total Individual Score	Risk Level	Corrective Action
1	28 - 49	Low	No repairs are needed yet
2	50 - 70	Moderate	Improvement required
3	71 - 91	High	Immediate action is required
4	92 – 112	Very High	Comprehensive action is needed as soon as possible

Sumber: Tarwaka (2019)

This study found an average total score of 54.2 for musculoskeletal complaints, which is categorized as moderate. This requires corrective action on the work tools used by workers. In this study, the truck tires weighed 37 kg without air and 37.5 kg after being inflated. Musculoskeletal complaints in truck tire installation workers are a result of the heavy truck tires and unnatural working postures, where the back is bent, and the head is raised. These results align with research by Azwir et al. (2021), which reports that uncomfortable postures during truck tire installation result from manual handling, leading to symptoms of disorders, particularly in the lower back**.** Workers experience pain and soreness in the neck, shoulders, upper and lower arms, wrists, waist, thighs, and legs. Work-related musculoskeletal disorders encompass all physical discomforts involving bones, muscles, ligaments, and nerves. Causes may include repetition, environmental factors, and uncomfortable or unnatural postures (Greggi et al., 2024). Based on the data in Table 1, a truck tire installation aid was designed using an ergo-mechanical approach. This method, which involves user participation, is called participatory ergonomics. Improving work systems through the application of participatory ergonomics methods can reduce ergonomic hazards or risk factors from previously high-risk to safer levels and improve work performance (Riyan et al., 2023; Thongchoomsin et al., 2025). Work systems that can cause discomfort, fatigue, or musculoskeletal disorders among workers are among the factors contributing to ergonomic hazards. Participatory ergonomics methods involve workers or users through training, discussions, and structured meetings to identify problems, implement improvements, and evaluate ergonomic outcomes (Fulmer et al., 2022). Ergonomic hazards arise from unnatural work postures, repetitive movements, excessive loads, and work tool designs that are not appropriate for the worker's abilities and anthropometry. The tool design uses anthropometric data from workers who install truck tires. The anthropometric data and percentiles for truck tire installation workers are presented in Table 3. The normal standard value (Z_x) of the 5th percentile is 1.65, so from Equation (1), the 5th percentile is obtained as $P_5 = \overline{X} - (1.65 \text{ x } \sigma)$. Table 3 presents anthropometric data from five workers who served as the basis for designing a truck tire installation tool. The body dimensions measured included standing elbow height, palm length, knee height, foot length, and horizontal standing reach. These dimensions were chosen because they directly relate to the worker's working posture, range of motion, and interaction with the tool.

Table 3. Anthropometric Data of Workers Required for the Design of Truck Tire Installation Tools

No.	Body Dimensions	Sample					Mean	Standard Deviation	5th percentile (cm)
		1	2	3	4	5			
1	Standing elbow height (cm)	95	105	101.5	98.5	99.5	99.9	7.0055395	88.3
2	Palm length (cm)	6	9	8	7	7.5	7.5	2.118034	4.0
3	Knee height (cm)	40	47	45.5	42.5	44	43.8	5.1272174	35.3
4	Foot length (cm)	22	26	24.5	23.5	23.6	23.92	2.7822938	19.3
5	Standing horizontal reach (cm)	52.5	65	61	56.5	59	58.8	8.9007843	44.1

Table 4. Truck Tire Installation Tool Dimensions based on 5th Percentile

No.	Body Dimensions	Usage	Dimensions (cm)
1	Standing elbow height	Work tool handle height	88.3
2	Palm length	Handle diameter	4
3	Knee height	Maximum height limit for tire lifters	35.3
4	Foot length	Lifting base length	19.3
5	Standing horizontal reach	Maximum forward reach	44.1

The measurement results showed variation in workers' anthropometric measurements, with an average standing elbow height of 99.9 cm (SD 7.01 cm). Therefore, all dimensions of the tool were designed using 5th-percentile values to ensure the safety and comfort of small-stature workers, as shown in Table 4. The 5th percentile values used include a standing elbow height of 88.3 cm as the tool grip height, a palm length of 4.0 cm as the basis for determining the grip diameter, a knee height of 35.3 cm as the maximum limit for the tire lift base height, a foot length of 19.3 cm as the length of the lift base, and a standing horizontal reach of 44.1 cm as the maximum forward reach. This approach ensures that the truck tire mounting tool can be used ergonomically, safely, and inclusively, while minimizing the risk of unnatural working postures and musculoskeletal disorders.

Based on the workers' anthropometric data in Table 3, the average values and standard deviations of body dimensions were obtained and used as the basis for designing a truck tire installation aid. To ensure the safety and comfort of workers with relatively small body sizes, all tool dimensions were based on the 5th-percentile body size. The dimensions of the truck tire installation aid were determined based on workers' anthropometric data, using the 5th percentile to accommodate small-bodied workers and to ensure safety and comfort, as recommended in ergonomic design principles (Pheasant & Haslegrave, 2006; Kroemer et al., 2019). The translation of the 5th percentile values into the tool's technical dimensions is shown in Table 4, and its implementation is illustrated in the 2D sketch in Figure 4 and in the tool design in Figures 5 and 6.

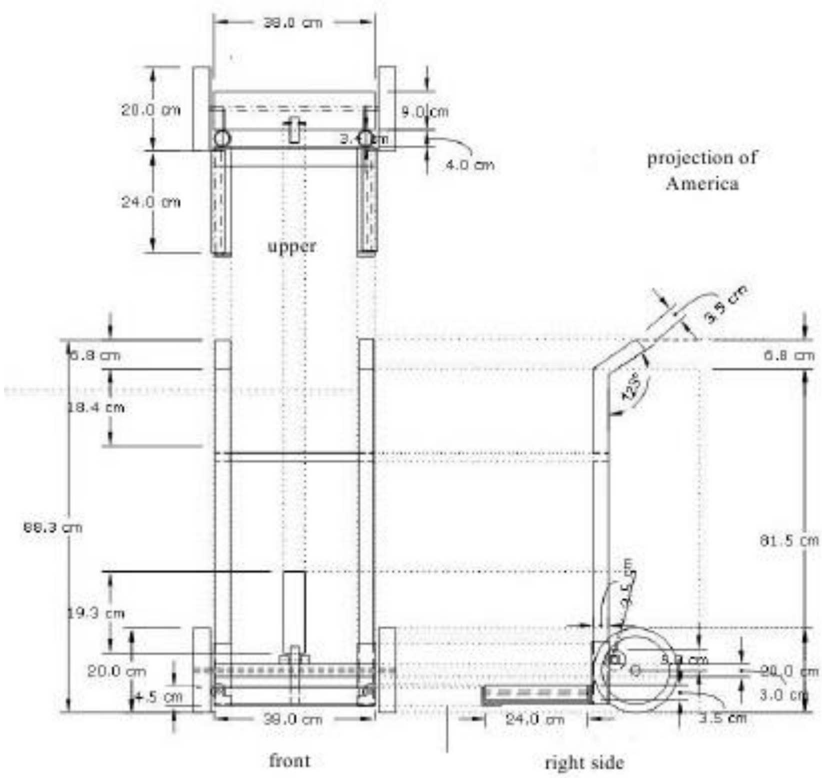


Figure 4. 2D Sketch of an Ergonomic Truck Tire Installation Tool

The tool handle diameter is set to 4.0 cm, corresponding to the 5th percentile of palm length, to ensure a comfortable and stable grip. The maximum height of the tire lift base in the figure is set at 35.3 cm, corresponding to the 5th percentile of knee height, to minimize squatting and bending. The tire lift base is designed to be 19.3 cm long, based on the 5th-percentile foot length, to provide adequate stability for smaller workers. Furthermore, the maximum forward reach in the design is limited to 44.1 cm, corresponding to the 5th percentile for standing horizontal reach, to prevent excessive reaching. Thus, the truck tire mounting tool has been ergonomically designed to be safe and inclusive, with the potential to reduce the risk of unnatural working postures and musculoskeletal disorders among workers. The ergo-mechanical approach ensures a neutral working posture, improves user safety and comfort, and reduces the risk of musculoskeletal disorders during truck tire mounting.

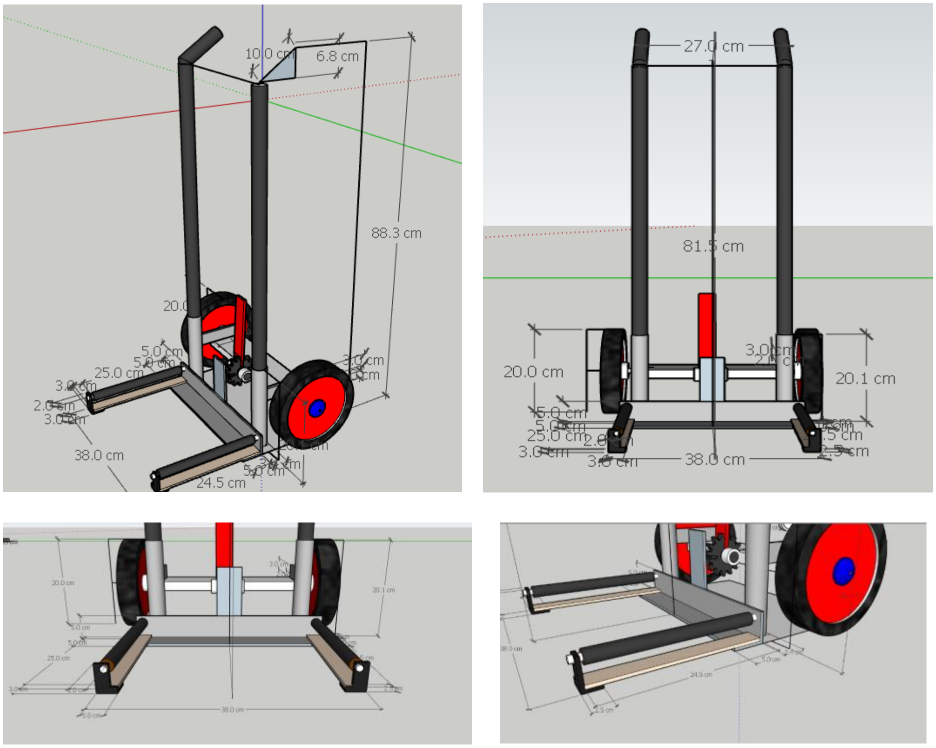


Figure 5. Ergonomic Truck Tire Installation Tool Design

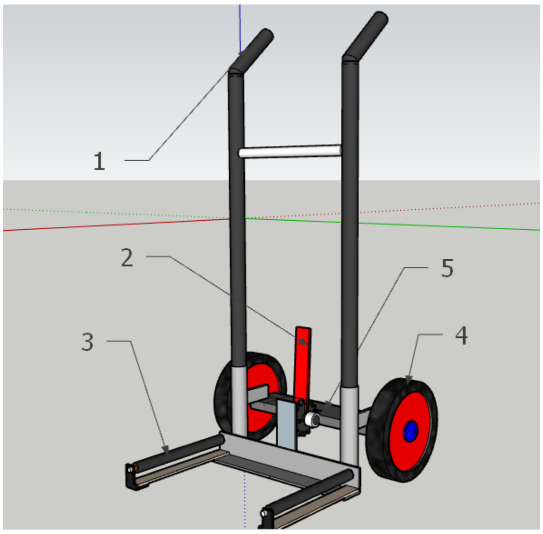


Figure 6. Ergonomic Truck Tire Installation Tool Parts

The proposed truck tire installation tool design has been developed based on a 5th-percentile anthropometric analysis and ergonomic principles, thereby conceptually meeting the user's working posture requirements. However, this research remains limited to the design stage, without prototype creation and testing, and includes a limited number of anthropometric samples; further research is needed to develop prototypes and conduct functional, ergonomic, and biomechanical tests to validate the tool's performance and safety under real working conditions.

CONCLUSION

Based on analysis of musculoskeletal complaints using the Nordic Body Map, truck tire installation workers exhibit a moderate risk, with an average score of 54.2, indicating a need to improve the work system and tools. Complaints are primarily attributable to unnatural work postures, such as bending and manual lifting. To address these issues, a truck tire installation aid was designed using an ergo-mechanical approach based on worker anthropometric data. All dimensions of the tool design are determined using the 5th percentile value to accommodate small workers and improve work safety and comfort. The results of the truck tire installation tool design based on the ergo-mecanical approach are that the truck tire installation tool consists of a handle with a diameter of 4 cm and a height of 88.3 cm, a lifting base measuring 19.3 × 5 cm with a maximum height of 35.3 cm, a tire rotating base with a length of 24 cm and a diameter of 3.5 cm, a wheel with a diameter of 20 cm, and a 6-tooth gear motor mechanism with a diameter of 4.5 cm with a 13 cm long 412H chain, all dimensions of which are designed based on the 5th percentile of worker anthropometry to ensure neutral standing posture, stability, and work comfort. The results of translating anthropometric data into design indicate that the proposed device has the potential to improve work posture and reduce the risk of musculoskeletal disorders. However, this research remains limited to the conceptual design stage, without the creation and testing of a physical prototype, and involves a small number of samples. Therefore, further research is needed to support prototype development, functional and ergonomic testing, and biomechanical evaluation to validate the device's effectiveness and safety in real-world work conditions.

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