

Performance evaluation of the truck tire mounting process based on work time and physiological workload

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ABSTRACT

Truck tire mounting is a manual, physically demanding activity that can impose a physiological load on workers. Previous research has led to the development of a truck tire mounting tool based on an ergo-mechanical approach that accounts for workers' anthropometric characteristics. This study aims to evaluate the performance of a newly developed tool by comparing a conventional method with the method using the new tool, based on installation time and workers' physiological responses. Testing was conducted on five male workers, comparing installation time, heart rate change (Δ HR), and Cardiovascular Load (%CVL) between the two methods. The magnitude of the difference between the two conditions was also evaluated using Cohen's d_z effect size for paired data. The results show that the mean setup time decreased from 4.08 to 2.92 minutes, a reduction of 28.48%. The mean Δ HR decreased from 31.8 to 15.8 bpm (a 50.3% reduction), while the mean %CVL decreased from 26.34% to 13.06% (a 50.42% reduction). Effect size analysis reveals consistent differences between the two methods regarding installation time, Δ HR, and %CVL. The study results indicate that using the new tool could improve the efficiency of the tire installation process while reducing workers' cardiovascular response. However, the limited number of subjects means that the results of this study need to be viewed as initial experimental evidence and cannot be generalised to a wider working population.

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INTRODUCTION

Mounting truck tires in small workshops is a manual task that places physical demands on workers during handling and positioning. Work activities involving high physical demands can elevate a worker's cardiovascular response; consequently, pulse rate measurements can serve as an indicator for evaluating physiological workload during the task. Research on a variety of manual work activities shows that heart rate can be used to describe a worker's response to physical load, either through direct

measurements or heart rate-based indices (Santos et al., 2023; Kraft et al., 2023; Pavlíková et al., 2024). A systematic review also indicates that heart rate measurement is one of the most widely used objective approaches for assessing cardiovascular load in the workplace (Dias et al., 2023).

Efforts to reduce the physical demands of the tire mounting process can be made by developing devices that assist workers in handling and positioning tires. Previous research has involved the development of a truck tire mounting tool using an ergo-mechanical approach that takes into account the workers' anthropometric characteristics. The design resulted in a prototype tailored to workers' body dimensions to improve interaction between workers and the tool during tire installation (Susana et al., 2026). The use of assistive devices in manual material handling activities is an ergonomic approach that can help reduce physical demands and musculoskeletal risks for workers, particularly in tasks involving loads, repetitive movements, and unfavourable working postures (Hilmi et al., 2024; Nuryawan & Nurkertamanda, 2024). Experimental studies on manual material handling activities also indicate that the use of assistive devices can result in biomechanical responses that differ from those of manual methods; therefore, the effectiveness of such devices needs to be evaluated based on actual usage conditions (Rouhani et al., 2024). Therefore, the development of work tools requires not only considering the compatibility between tool characteristics and the user but also verifying this through testing of process performance and the resulting work demands.

The effectiveness of an ergonomic device cannot be assessed solely based on design suitability and ease of use; it must also be verified through objective measurements under actual working conditions. Research on manual material handling activities indicates that load characteristics and handling methods are linked to changes in workers' heart rates; consequently, physiological responses can be used to evaluate the physical demands of a given activity (Hosseini et al., 2024). Other research on ergonomics interventions in manual material handling tasks indicates that using the developed device can change workers' biomechanical loads and physiological responses compared with manual methods (Shakourisalim et al., 2024; Sharma et al., 2025). Furthermore, the development of manual handling aids for material transfer tasks demonstrates that the device's design characteristics can influence workers' physical responses during work activities (Ahmad et al., 2025). Therefore, the developed prototype needs to be verified through experimental testing under actual working conditions to simultaneously evaluate the impact of its use on process performance and the workers' physiological load. This approach is necessary to ensure that the improvement in tool performance is not only reflected in changes in task duration but is also accompanied by changes in the physiological demands placed on the worker relative to conventional methods.

The effectiveness of the developed tool needs to be evaluated using indicators that reflect changes in process performance and the physical demands placed on workers. Work time analysis can be used to evaluate changes in process efficiency following modifications to work methods or configurations (Turk et al., 2022). In manual material-handling activities, experimental testing is

required to determine the effects of changes in task characteristics and handling conditions on workers' physical responses (Adhaye et al., 2023). Furthermore, the pulse rate can serve as an indicator of the physiological response to varying demands of manual activities (Ramadan & Alferdaws, 2022). Based on these considerations, this study aims to evaluate the performance of the developed tool during the truck tire mounting process by comparing the conventional method with the method using the developed tool, based on mounting time and workers' pulse rate responses. Physiological responses were analysed through changes in pulse rate (ΔHR) and Cardiovascular Load (%CVL) to determine changes in physiological demands following the use of the tool.

METHOD

This study is a comparative experimental investigation aimed at evaluating the performance of the truck tire mounting process using both the conventional method and a newly developed method. The developed method represents the physical implementation of a design created in a prior study, which used an ergo-mechanical approach that accounted for workers' anthropometric characteristics (Susana et al., 2026). Previous research has focused on device design, specifically adjusting device dimensions to workers' anthropometry (Susana et al., 2026). Therefore, this study represents a subsequent phase focusing on the experimental evaluation of the device during the truck tire mounting process. The evaluation is based on two sets of parameters: process performance-specifically mounting time-and workers' physiological responses, namely changes in heart rate and Cardiovascular Load (%CVL).

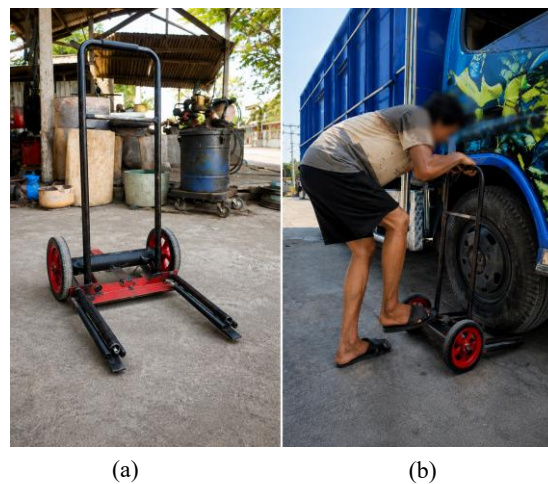


Figure 1. Developed Prototype and its Application in Truck Tire Mounting: (a) Physical Prototype; (b) Experimental Application on A Truck

Testing was conducted using the same subjects for both methods (within-subject design), such that each worker served as their own control. This approach was employed to minimise the influence of individual characteristic variations on the test results. The study subjects consisted of five workers from a small workshop involved in truck tire mounting activities. The workers' ages are 23, 30, 25, 24, and 22 years, respectively. The five workers performed the tire-mounting process using two methods: the conventional method and a newly developed method. Each worker underwent testing under both

conditions, allowing for a paired comparison of mounting times and physiological responses. Worker age is a factor used to determine maximum heart rate when calculating physiological workload. The device used in this study is a physical prototype developed based on an ergo-mechanical design and worker anthropometric considerations reported in previous research (Susana et al., 2026). The physical prototype is shown in Figure 1. In a previous study, the device was analysed in terms of its design and the suitability of its dimensions regarding the workers' anthropometric characteristics. In this study, the device was used as a test object to evaluate actual performance during the truck tire mounting process.

Research variables include installation methods (conventional and development results), as well as performance and physiological parameters such as pulse rate before activity, pulse rate after activity, change in heart rate (ΔHR), cardiovascular load (%CVL), and installation time. Testing was carried out directly in the workshop work environment using one truck tire as the installation object. Each worker performs installation tasks using both the conventional method and the newly developed method. Before the installation activity, the worker is at rest, and their pulse rate is measured (HR_{before}). Next, the worker performs the tire installation process using the designated method. The time required to complete the installation of a single tire is recorded as the installation time. Once the installation process is complete, the worker's pulse is measured again as the post-activity pulse (HR_{post}). The same procedure is applied to both installation methods. Using the same subjects for both methods allows for a paired comparison of the installation time and physiological responses of each worker.

Installation time is used as a process performance indicator. Measurements are taken from the start of the installation process until the installation of a single tire is completed. The difference in installation time (Δt) between the two methods is calculated using Equation (1).

$$\Delta t = t_k - t_p \quad (1)$$

t_k represents the installation time using the conventional method (minutes), and t_p is the installation time using the developed method (minutes). The percentage change in installation time is calculated using Equation (2).

$$p_t = \frac{t_k - t_p}{t_k} \times 100\% \quad (2)$$

The p_t value indicates the percentage reduction in installation time achieved using the developed method compared to the conventional method.

Pulse rate is used as an indicator of the worker's physiological response to the tire-mounting activity. Measurements were taken before and after the mounting activity for each method. To demonstrate the increase in pulse rate occurring during work or the mounting activity, the change in pulse rate (ΔHR) was calculated using Equation (3).

$$\Delta HR = HR_{\text{work}} - HR_{\text{rest}} \quad (3)$$

HR_{work} is the heart rate after activity (bpm), and HR_{rest} is the heart rate before activity (bpm), and bpm denotes beats per minute. Physiological workload is calculated using the Cardiovascular Load

percentage (%CVL), as shown in Equation (4) (Marciniak et al., 2021; Wanke et al., 2020; Dias et al., 2023).

$$\%CVL = \frac{100 \times (HR_{work} - HR_{rest})}{HR_{max} - HR_{rest}} \quad (4)$$

HR_{max} is the maximum heart rate (bpm) = $220 - \text{age}$ (Sammito et al., 2024); HR_{work} is the heart rate during activity (bpm); and HR_{rest} is the heart rate prior to activity (bpm). The %CVL value is used to compare the workers' physiological workload between the conventional method and the newly developed method.

The magnitude of the difference between the conventional method and the developed method for each parameter-namely installation time, change in heart rate (ΔHR), and Cardiovascular Load (%CVL)-was evaluated using Cohen's effect size for paired data, based on Equation (5) (Lakens, 2013).

$$d_z = \frac{\bar{D}}{SD_D} \quad (5)$$

d_z represents the effect size of paired changes, $\bar{D}$ is the average rate of change/difference, SD_D is the standard deviation of the change/difference.

RESULTS AND DISCUSSION

Testing was conducted to evaluate the performance of the newly developed tool during the truck tire mounting process by comparing it with the existing tool. Process performance was assessed based on the time required to mount a single truck tire, while the workers' physiological demands were evaluated based on changes in heart rate and Cardiovascular Load (%CVL). The tests involved five workers performing the same task under both methods, allowing the resulting differences to illustrate changes in process performance and physiological responses following the use of the new tool. Installation time testing was conducted to determine changes in process performance following the implementation of a new tool for truck tire installation activities. The results of measuring the time required for a single tire installation across five workers are presented in Table 1, while the comparative time patterns between the use of the old tool and the new tool are shown in Figure 2.

Table 1. Time to Install One Truck Tire

Worker	Old Tool (minute)	New Tool (minute)	Reduction (%)
1	3.80	2.59	31.84
2	4.20	3.10	26.19
3	3.90	2.70	30.77
4	4.10	3.00	26.83
5	4.40	3.20	27.27
Average	4.08	2.92	28.48

Based on Table 1 and Figure 2, the installation time using the new tool was shorter than that of the old tool for all workers. With the old tool, installation time ranged from 3.80 to 4.40 minutes, whereas

the new tool resulted in times of 2.59 to 3.20 minutes. A reduction in time was observed for all workers, with individual percentage reductions ranging from 26.19% to 31.84%.

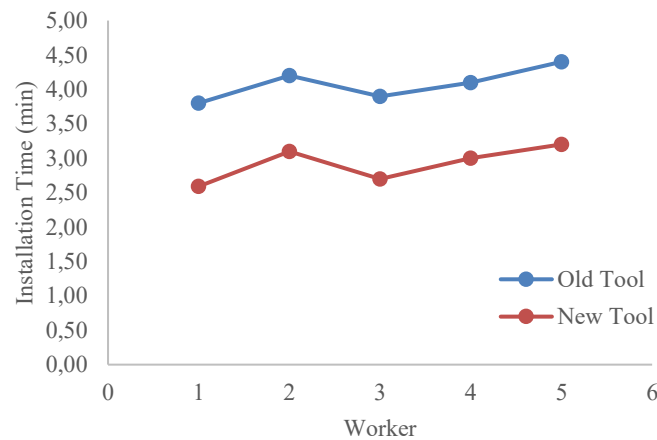


Figure 2. Comparison of Truck Tire Installation Time Using the Old and New Tools for Five Workers

The results indicate that the implementation of the new tool led to a consistent trend of increased efficiency in the tire installation process across all five workers. Overall, the average installation time decreased from 4.08 minutes with the old tool to 2.92 minutes with the new tool—a reduction of 1.16 minutes (28.48%). This reduction demonstrates that changes to equipment and work methods can impact the performance of manual processes. These findings align with Suranuntchai & Chutima (2023), who demonstrated that implementing process improvements integrating ergonomic approaches and changes to work methods can reduce cycle time in manual assembly processes. In that study, the evaluation involved observing workflows, worker movements, and cycle times both before and after the process improvements. From an engineering perspective, the reduction in installation time can be attributed to changes in how workers handle and position the tires during the work process. In a previous study, the tool used in this test was developed using an ergo-mechanical approach that accounted for workers' anthropometric characteristics (Susana et al., 2026). Adjusting the tool's dimensions to user characteristics provides a design basis that subsequently requires verification through testing under actual working conditions. The results of this study indicate that the design not only yields an anthropometrically suitable prototype but also tends to enhance process performance when used by workers. An experimental evaluation approach under actual working conditions is also important, as changes to work systems can affect both process performance and workers' physical condition. Gervasi et al. (2023), for instance, demonstrated that comparing manual work conditions with those supported by technology can be evaluated by simultaneously assessing process performance indicators and worker responses. The 28.48% reduction in installation time provides an initial indication that the new tool can improve the efficiency of the tire installation process. However, this performance improvement is insufficient to fully characterise the tool's effectiveness, as the device's use can also increase the physical

demands placed on the worker. Therefore, the subsequent discussion focuses on changes in pulse rate to evaluate workers' physiological responses to the new equipment.

The difference in installation times between the old and new tools needs to be further examined in terms of the workers' physiological responses during the tire installation process. Pulse rate is used as an indicator of physiological response because changes in pulse rate reflect the body's response to the demands of physical activity. Therefore, measurements were taken before and after the task on the same workers to compare the changes in physiological response associated with using the old versus the new tool. The results of the pulse rate measurements and the changes in pulse rate (ΔHR) are presented in Table 2.

Table 2. Worker's Pulse Before and After Tire Installation

Worker	Old Tool Before (bpm)	Old Tool After (bpm)	ΔHR Old (bpm)	New Tool Before (bpm)	New Tool After (bpm)	ΔHR New (bpm)
1	84	106	22	87	93	6
2	67	105	38	71	92	21
3	75	112	37	76	91	15
4	76	109	33	74	92	18
5	72	101	29	70	89	19
Average	74.8	106.6	31.8	75.6	91.4	15.8

Based on Table 2, heart rate increased after workers completed the tire-mounting activity using both methods. With the old tool, the post-work heart rate ranged from 101 to 112 bpm, whereas with the new tool, it ranged from 89 to 93 bpm. A more distinct difference is evident in the change in heart rate (ΔHR). All workers exhibited lower ΔHR values when using the new tool compared to the old tool, as also shown in Figure 3.

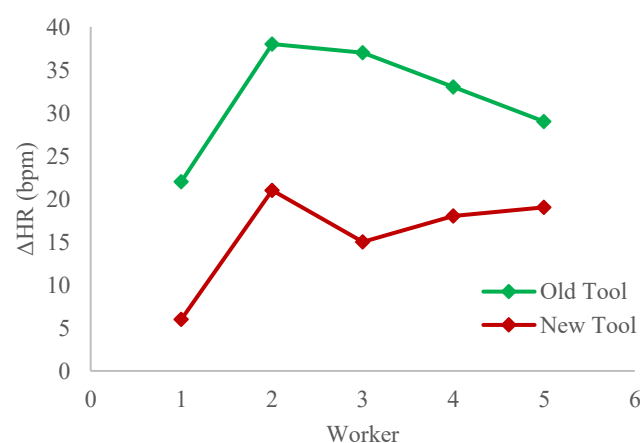


Figure 3. Comparison of Pulse Rate Changes (ΔHR) Using the Old and New Devices

The average change in pulse rate when using the old device was 31.8 beats/minute, whereas with the new device, it was 15.8 beats/minute. Thus, the average change in pulse rate decreased by 16.0 beats/minute, or approximately 50.3%. This decrease indicates that using the new tool was associated

with a lower physiological response during the installation process. Heart rate can serve as a physiological indicator for monitoring physical exertion during manual material handling activities (Umer et al., 2022). The use of pulse rate as an indicator of physiological response has also been applied to evaluating physical workload in manual tasks. Pandit (2023) demonstrated that pulse rate can be used to assess physiological workload during physical work activities. In a manufacturing context, Gervasi et al. (2023) showed that changes in the type of support provided during manual assembly tasks can influence operators' physical demands and physiological responses. These results indicate that the changes in physiological responses observed in this study should be considered part of the evaluation of the device's effectiveness, rather than merely fluctuations in pulse rate. The differences in pulse rate changes between the two methods were further evaluated using the Cardiovascular Load (%CVL) parameter to gain insight into the workers' cardiovascular load.

The %CVL parameter accounts for pre-work heart rate, post-work heart rate, and the worker's maximum heart rate, serving as a measure of cardiovascular demand relative to the worker's physiological capacity. Utilizing %CVL provides additional insight into cardiovascular demand by factoring in heart rate changes relative to maximum heart rate capacity. This approach has been used to evaluate physical workload in industrial settings, including tasks in machining and welding divisions, making it suitable for assessing the physiological demands of physically active jobs (Fatah & Mahachandra, 2024). %CVL has also been used to evaluate operator workload in industrial environments by comparing heart rate responses before and after task performance (Samosir & Sofiyanurriyanti, 2022). Furthermore, Hasibuan et al. (2021) used the CVL method to identify workers' physical workload in a production environment and determine the need for improvements based on %CVL values. Thus, %CVL can serve as an additional indicator for evaluating changes in cardiovascular demands resulting from the implementation of different work methods or equipment. Based on Table 3 and Figure 4, the %CVL values for all workers were lower when using the new tool compared to the old tool. With the old tool, %CVL values ranged from 19.47% to 30.89%, whereas with the new tool, they ranged from 5.45% to 17.65%. The average %CVL decreased from 26.34% with the old tool to 13.06% with the new tool, representing a reduction of 13.28 percentage points, or approximately 50.42%.

Table 3. %CVL Values for Workers Using Old and New Tools

Worker	Age (year)	HR _{max} (bpm)	%CVL	
			Old Tool	New Tool
1	23	197	19.47	5.45
2	30	190	30.89	17.65
3	25	195	30.83	12.61
4	24	196	27.50	14.75
5	22	198	23.02	14.84
Average			26.34	13.06

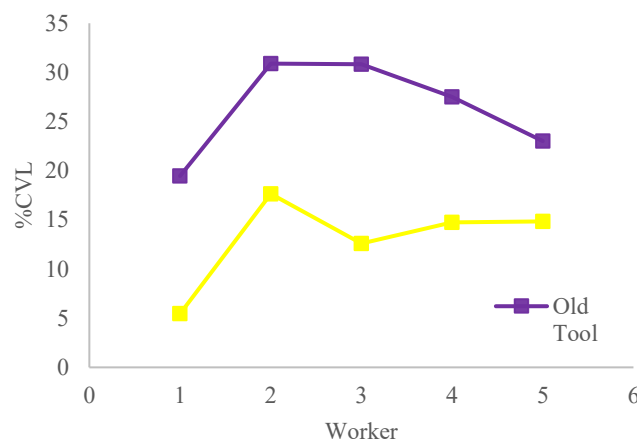


Figure 4. Comparison of Cardiovascular Load (%CVL) Using Old and New Tools

Based on Table 3 and Figure 4, the %CVL value associated with the new tool was lower than that of the old tool across all workers. The average %CVL decreased from 26.34% to 13.06%, a reduction of 13.28 percentage points (50.42%), while Δ HR dropped from 31.8 to 15.8 bpm (50.3%). The consistent decline in both indicators demonstrates that using the new tool was associated not only with a 28.48% reduction in installation time but also with a lower cardiovascular response. The use of %CVL as an indicator of cardiovascular load during physical activity has also been applied in industrial work settings (Yasmin et al., 2023; Pahlepi & Hadi, 2023). These results indicate that the new tool has the potential to improve process efficiency while simultaneously reducing the physiological demands placed on workers. However, as the testing involved only five workers, the findings should be viewed as reflecting trends under experimental conditions and cannot yet be generalized to the broader population of tire fitting workers.

In addition to comparing mean values and percentage changes, the magnitude of the difference between using the old tool and the new tool was evaluated using effect size. This analysis was employed to characterize the magnitude of changes in installation time, heart rate change (Δ HR), and Cardiovascular Load (%CVL). Since measurements were taken on the same workers under two conditions using the old tool and the new tool effect size was calculated using Cohen's d_z , derived from the ratio of the mean difference score to the standard deviation of the difference score (Lakens, 2013). The effect size approach to repeated measurement designs also needs to consider the characteristics of paired data and the purpose of interpreting the results (Morris & DeShon, 2002). Thus, effect size is used as an additional measure to describe the magnitude of the difference between the two conditions, not as a substitute for inferential statistical analysis. The results of effect size calculations for installation time, Δ HR, and %CVL are presented in Table 4. Based on Table 4, all parameters show consistent differences between the use of the old device and the new device, with Cohen's d_z values of 20.48 for installation time, 3.72 for Δ HR, and 3.71 for %CVL. This value indicates that the observed change is relatively large compared to the variation in difference scores among workers. The effect size results reinforce the descriptive findings that the use of the new tool is associated with reduced installation time

and workers' physiological responses. However, the effect size value should be interpreted with consideration of the paired design and the limited number of subjects. Especially at installation time, the very high d_z value is mainly driven by the small variation in difference scores across workers, so it is not appropriate to interpret it directly as a large causal effect of the tool on installation time.

Table 4. Effect size Changes in Performance and Physiological Responses

Parameter	Alat lama	Alat baru	Perubahan (%)	Cohen's (d_z)
Waktu pemasangan (menit)	4.08	2.92	28.48	20.48
Δ HR (bpm)	31.80	15.80	50.30	3.72
%CVL (%)	26.34	13.06	50.42	3.71

Overall, the test results show that the new tool improves process performance and workers' physiological responses. Installation time was reduced by 28.48%, while changes in heart rate (Δ HR) and Cardiovascular Load (%CVL) decreased by 50.3% and 50.42%, respectively. The effect size results also show consistent differences between the two methods in these three parameters. These findings indicate that the evaluation of the developed tool should not rely solely on anthropometric suitability but should also include verification through performance testing and assessment of physiological responses under actual usage conditions. Thus, the new tool has the potential to improve the efficiency of the tire-mounting process while simultaneously reducing cardiovascular strain on workers. However, since the testing involved only five male workers, the findings should be viewed as preliminary experimental evidence and cannot yet be generalized to the broader workforce.

CONCLUSION

Based on the test results, the newly developed tool demonstrated improved truck tire mounting performance and reduced physiological strain on workers compared to the previous tool. The average mounting time decreased from 4.08 to 2.92 minutes (a 28.48% reduction), while the average change in heart rate (Δ HR) dropped from 31.8 to 15.8 bpm (a 50.3% reduction). A decrease was also observed in the Cardiovascular Load (%CVL) value, falling from an average of 26.34% to 13.06% (a 50.42% reduction). Effect size analysis results indicate a consistent difference between the two methods across the three parameters. Overall, the developed tool has the potential to enhance installation process efficiency while simultaneously reducing cardiovascular strain on workers. However, as the testing involved only five male workers, these findings constitute preliminary experimental evidence and cannot yet be generalized to the broader worker population.

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