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STUDY OF PHYSICAL AND MENTAL WORKLOAD IN THE SMALL-SCALE TOFU INDUSTRY: AN ERGONOMIC PERSPECTIVE USING CARDIOVASCULAR LOAD AND NASA-TLX

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Abstract

Human labor is still widely used by Micro, Small, and Medium-sized Enterprises (MSMEs) in Indonesia, especially those in the food processing sector, such as the tofu industry. Manual labor can place significant physical and mental demands on workers, especially when the number of workers is not proportional to the demands of the tasks assigned. Excessive workload in these aspects may result in fatigue and decreased productivity. This study aims to assess both physical and mental workloads in the production workstation by identifying workload intensity, including mental and physical aspects experienced by workers. The workloads with the greatest levels will be determined for more research and solutions. Cardiovascular Load (CVL) is used to measure physical workload, and National Aeronautical and Space Administration Task Load Index (NASA-TLX) is used to assess mental workload. These methods have identified varying degrees of physical and mental strain across different job roles. The results show that the cooking and filtering phases are key areas that demand particular focus. Workers in the cooking and filtering areas had respective CVL values of 30.60% and 30.24%, while the mental workloads assessed using the NASA-TLX reached 80.33 and 81.33.

Keywords: ***workload, cardiovascular load (CVL), NASA-TLX***

INTRODUCTION

Every work activity requires varying levels of physical effort and mental concentration. Excessive workload has the potential to trigger fatigue, stress, and even lead to decreased productivity, health issues, and an increased risk of accidents (Medeline et al., 2020). In the field of ergonomics, workload levels are generally adjusted to match workers' physical endurance and mental capacity to prevent negative impacts on health and performance (Syaifunnawal & Budiani, 2023). If tasks exceed a worker's capacity, the risk of work-related fatigue increases (Hermawan et al., 2017). Physical workload can result in various adverse effects, including musculoskeletal disorders, lower back pain, and even the risk of fractures. Additionally, excessive workload may contribute to psychological issues such as emotional stress, headaches, digestive problems, and heightened irritability (Poó et al., 2018). Moreover, excessive mental workload can have negative effects. According to (Hakiim et al., 2018), these effects may include memory lapses, difficulty focusing, heightened anxiety, increased environmental sensitivity, restlessness, and a tendency to feel hopeless. Workers who depend primarily on manual labor often experience high workload levels.

Micro, Small, and Medium Enterprises (MSMEs) in Indonesia predominantly depend on human labor for their production processes, particularly in the food processing sector. An example is the Pak Parto's small-scale tofu industry, which manufactures tofu through several stages, including grinding, cooking, filtering, molding, flipping, and cutting. Most of these processes are still performed manually, demanding a high level of physical effort from workers. Furthermore, labor shortages have resulted in only five workers in 2025 being responsible for carrying out production stages. Based on the interview, there has been a decline in the number of workers since the COVID-19 pandemic until now. However, this decrease contrasts with the rising production demand. Tofu production has actually increased over the past two years. Before the COVID-19 pandemic, the amount of soybeans used as the main ingredient for tofu production reached a maximum of nine tons per month. Currently, demand has risen, even surpassing pre-pandemic levels, with production now reaching eleven tons per month. The decline in the number of workers, coupled with the increase in tofu production in the industry, has resulted in a heavier workload for the remaining workers. The labor shortage also requires workers to take on multiple roles, such as in the cooking and filtering processes, which now must be handled by a single person. This situation increases workload of workers (Haikal, 2024). Both physical and mental workload can significantly affect production efficiency, product quality, and worker health.

Ergonomic approaches can effectively identify workload in industries. From a physical perspective, ergonomic studies in the tofu industry have highlighted substantial musculoskeletal risks for workers, primarily caused by improper work postures and repetitive movements, especially for manual material handling (MMH) activities (Amalia et al., 2024). In addition to physical workload, mental workload in the tofu industry also requires careful consideration. Mental workload is a significant factor influencing employee performance, with studies showing high levels of mental and physical demands among tofu industry workers (Meri et al., 2023).

Referring to the background context outlined earlier, this study aims to identify both physical and mental workloads in small-scale tofu industries by applying an ergonomic approach. The findings are expected to highlight the work stages with the highest workload and provide recommendations for improvements that enhance worker comfort, health, and productivity in the industry.

LITERATURE REVIEW

Several studies have been conducted in the tofu industry related to ergonomic evaluations. Ergonomic studies in tofu industries have identified significant musculoskeletal risks for workers due to non-ergonomic work postures and repetitive tasks (Nurfajriah & Arifati, 2018; Lestantyo et al., 2022). This research is a continuation of Amalia's study, which identified potential ergonomic hazards in MMH activities using measurement methods based on SNI 9011:2021 (Amalia et al., 2024). This study includes an analysis of workers' postures but does not assess the physical workload that impacts physiological changes in the body. Besides physical workload, it is also essential to assess mental workload in tofu industry phases. Excessive physical and mental workload may lead to fatigue, health issues, and burnout.

This literature review examines approaches to identifying physical and mental workload using ergonomic methods. Physical workload can be measured through physiological indicators like heart rate, %HRR (Thamsuwan et al., 2023), %CVL (Septio et al., 2020; Peña et al., 2021), and oxygen consumption (Yuliani et al., 2021). Mental workload is often assessed using psychological questionnaires like SWAT (Angelo et al., 2022) and NASA-TLX (Alfonso et al., 2022).

The evaluation of physical workload can be conducted using the Cardiovascular Load (CVL) method, which assesses fatigue levels by examining the ratio between heart rate during activity and maximum heart rate. The study conducted by Aryanny & Baitil (2021) measured physical workload using the CVL method in a production unit. The findings revealed that operators responsible for plastic crushing and product molding had CVL percentage values classified as requiring improvement. Studies have demonstrated its utility in various industries, including construction and manufacturing. CVL analysis can identify workers experiencing excessive physical strain, allowing for targeted improvements in work conditions (Hasibuan et al., 2021). Research has also shown a significant correlation between CVL-measured workload and worker fatigue (Sari et al., 2022). CVL was measured in soybean pulp filtering workers in the tofu industry following a workload design intervention; however, the study did not assess the mental workload aspect (Hutabarat, 2023).

Furthermore, the method's versatility is evident in CVL application alongside other techniques like NASA-TLX for comprehensive workload assessment (Puteri & Sukarna, 2017). The study conducted by Adikarana et al. (2022) applied the NASA-TLX to evaluate the mental workload of workers in a metal stamping production division, resulting in an average weighted workload (WWL) score fell into the high category. NASA-TLX was also used to assess mental workload in a tofu industry in Padang, where the WWL score was found to be high (Meri et al., 2023). However, this study did not include a quantitative evaluation of physical workload for comparison.

A comprehensive analytical approach is essential for identifying and measuring the intensity of workload experienced by workers. Physical workload can be assessed through the CVL method. On the other hand, the mental workload of tasks can be examined using the NASA-TLX, which gauges workers' perceptions of task difficulty. Previous studies have demonstrated that the CVL and NASA-TLX methods are effective in assessing both physical and mental workload among workers. Therefore, this research will utilize the methods to evaluate workload levels across different production phases at tofu industry. The findings from this study will provide a basis for formulating improvement strategies to enhance work efficiency and employee well-being.

METHOD

This research was carried out at the small-scale tofu industry, Tahu Pak Parto, located in Semarang. Data collection and direct observations were conducted from early December 2024 to late January 2025. The study primarily focused on evaluating workload across different workstations in the tofu production process to gain a comprehensive understanding of the working conditions. This study employs a cross-sectional approach, using the CVL method to objectively measure physical workload and the NASA-TLX method to subjectively assess workers' mental workload.

CVL data collection involved measuring workers' heart rates during both work and rest periods using an oximeter. Meanwhile, NASA-TLX data were obtained through questionnaires given to production workers, enabling them to assess workload by comparing various workload dimensions. Additionally, interviews were conducted to gather information about production challenges and to capture insights from both the owner and workers. This method aimed to analyze factors affecting workload, identify obstacles, and explore potential improvements to enhance productivity and overall work comfort.

Physical workload is generally classified as manual activity, referring to conditions where job performance relies entirely on individuals as the primary source of power or control in performing tasks. Manual activities encompass various tasks that require direct physical involvement from workers and often involve repetitive movements in non-ergonomic postures, which can contribute to health issues such as musculoskeletal disorders ((Benos et al., 2020)). The estimation of the physical workload index is based on three heart rate or pulse categories: resting pulse, working pulse, and the difference between them (Widodo, 2008). The workload level is assessed by calculating the percentage increase in working pulse compared to the maximum pulse, represented as CVL. The %CVL value is derived using a formula.

$$\%CVL = \frac{100 \times working\ pulse - resting\ pulse}{maximum\ pulse - resting\ pulse}$$

The resting pulse represents the average heart rate measured before begins work activity, whereas the working pulse refers to the average heart rate recorded while performing job task. The maximum pulse differs for each person, depending on physical condition and age. It is determined using the formula 220 minus age for men, and 200 minus age for women (Tarwaka & Bakri, 2004). Classification of % CVL: CVL $\leq$ 30% (No fatigue occurs); 30% < CVL $\leq$ 60% (Required repairs); 60% < CVL $\leq$ 80% (Work in a short time); 80% < CVL $\leq$ 100% (Immediate action is required); CVL > 100% (Not allowed to work).

The evaluation of mental workload utilizes the NASA-TLX method as an analytical tool to assess the cognitive strain workers experience while performing tasks and responsibilities. This measurement considers six main parameters as assessment indicators (Basumerda, 2019): mental demand (MD), physical demand (PD), temporal demand (TD), effort (EF), performance (OP), and frustration level (FR). MD refers the level of cognitive and perceptual involvement required, such as observing, searching for information, and remembering. PD represents the amount of physical activity needed to perform tasks, including pushing, pulling, or controlling mechanical movements. TD indicates the degree of time pressure felt while performing a task. EF measures the intensity of cognitive and physical activity required to complete a task optimally. OP assesses the level of success in completing tasks and satisfaction with the achieved results. FR evaluates the extent of insecurity, despair, dissatisfaction, and disturbance experienced compared to feelings of security, satisfaction, comfort, and self-appreciation n the calculation process using the NASA-TLX method, the following steps are followed (Tubbs-Cooley et al., 2018): (a) Weighting Scores – respondents evaluate two different dimensions using a paired comparison approach, with a total of 15 comparisons required for the six dimensions; (b) Assigning Rating Scores – each descriptor is assigned a scale from 1 to 100, and employees determine scores based on their perceived workload while performing tasks; (c) Calculating Product Values – obtained by multiplying the assigned weights and scores; (d) Weighted Workload (WWL) – derived by summing the product values of the six indicators; (e) Calculating the Workload Score – determined by dividing the WWL by the total weight of 15; and (f) Interpreting the workload score. The equations used to calculate product values, WWL, and workload score are as follows.

Product Values $= rating \times weighting\ factor$

WWL $= \sum product\ values$

NASA-TLX score $= \frac{WWL}{15}$

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Workload scores are categorized into three levels: (a) below 50 is classified as low; (b) between 50 and 80 is considered medium; and (c) above 80 is categorized as high (Arasyandi & Bakhtiar, 2016).

RESULTS AND DISCUSSION

The tofu production process at Pak Parto's small-scale tofu industry consists of six stages performed at production workstations: soybean soaking, grinding, cooking, filtering, molding, and cutting. The results and discussion include the characteristics of the observed workers, the measurement and analysis results of CVL and NASA-TLX, and relevant improvement recommendations based on the findings.

Respondent Characteristics

The respondents in this study are workers involved in the tofu production process, consisting of five workers responsible for carrying out the production stages with those characteristics. The workers' ages range from 19 to 45 years old, with varying levels of experience in the tofu-making industry. The duration of employment varies, from 1 year to 23 years, indicating differences in expertise and familiarity with the production process. Each worker has specific roles, including soybean grinding, cooking, filtering, molding, and cutting, with some handling multiple tasks simultaneously.

1. P1: Soybean soaking, grinding, and transferring to the cooking stage (job tenure: 1 year)
2. P2: Cooking and filtering – manage dual tasks (job tenure exp: 20 years)
3. P3: Cooking and filtering have similar tasks to P2 (job tenure: 15 years)
4. P4: Molding – transferring soybean starch in molds, flipping mold boards (job tenure: 2 years)
5. P5: Cutting – slicing tofu (job tenure: 23 years)

These characteristics provide insights into the workforce structure and workload distribution within the tofu production process.

Physical Workload Analysis Using Cardiovascular Load

The resting pulse was measured at 06:30 and 14:00, while the working pulse was recorded at 09:00 and 11:00. The results of heart rate measurements and CVL are presented in Table 1 as follows.

Table 1. Results of %CVL Measurement for Tofu Workers

worker	Age (yo)	Job	Resting Pulse			Working Pulse			Max Pulse	%CVL	Classification
			1	2	$\bar{X}$	1	2	$\bar{X}$			
P1	19	Soaking, grinding	75	82	78,5	101	98	99,5	201	17,14	No fatigue occurs
P2	43	Cooking, Filtering	83	88	85,5	115	112	113,5	177	30,60	Required repairs
P3	35	Cooking, Filtering	80	85	82,5	114	115	114,5	185	31,22	Required repairs
P4	24	Molding	79	87	83	120	108	114	196	27,43	No fatigue occurs
P5	45	Cutting	82	85	83,5	101	98	99,5	175	17,49	No fatigue occurs

The highest average working pulse was recorded in the Cooking and Filtering process (P2 and P3). These two workers had the highest average working heart rates compared to other workers and production processes. An increase in a worker's pulse may indicate a higher level of fatigue, which can ultimately lead to a decrease in work performance, especially in tasks involving physical activity. Heart rate variability analysis has shown significant differences between working and resting conditions, further supporting its utility in quantifying fatigue (Wu et al., 2018). Certain workers, particularly those involved in cooking and filtering, perform physically demanding tasks that require repetitive movements and manual labor. The maximum heart rate or pulse in adults ranges from 180 to 200 beats per minute, and this condition can generally be sustained for only a few minutes during maximum physical activity (Setiawan et al., 2014). It can be observed that the maximum heart rate of the five workers mentioned above remains within the normal range, as it still ranges between 180 and 200 beats per minute.

Based on the physical workload calculation using CVL, the highest physical strain among workers at tofu industry was observed in the cooking and filtering, with %CVL values of 30.60% and 31.22%, respectively. These tasks fall into the category of physical workloads that necessitate intervention and improvement. The filtering process still depends on manual labor and traditional equipment, requiring workers to rapidly shake the filter. Furthermore, this task is performed continuously for six hours without breaks, with workers remaining in a standing position throughout. In addition to that, employees are responsible for both cooking and filtering simultaneously, which increases the workload intensity and the need for a faster work pace.

Mental Workload Analysis Using NASA-TLX

In evaluating mental workload, workers were provided with a questionnaire to assign weights and rate each indicator based on their preferences. The product values result from multiplying the weight by the rating provided by the workers, where the weight represents the importance of the factor, while the rating reflects the intensity of the workload subjectively experienced. Based on the product values obtained, P2, who is responsible for Cooking and Filtering, recorded the highest Effort (EF) score of 475, indicating that this task requires significant exertion. Meanwhile, P3, working in Cooking and Filtering 2, had a Mental Demand (MD) score of 255 and a Physical Demand (PD) score of 225, signifying high cognitive and physical demands. On the other hand, the milling process performed by P1 was found to have a lighter workload. The Frustration (FR) score of 0 suggests that this task does not cause significant mental strain or stress. However, in the molding section, P4 recorded the highest Frustration (FR) score of 325, indicating a considerable level of discomfort or work pressure in this task.

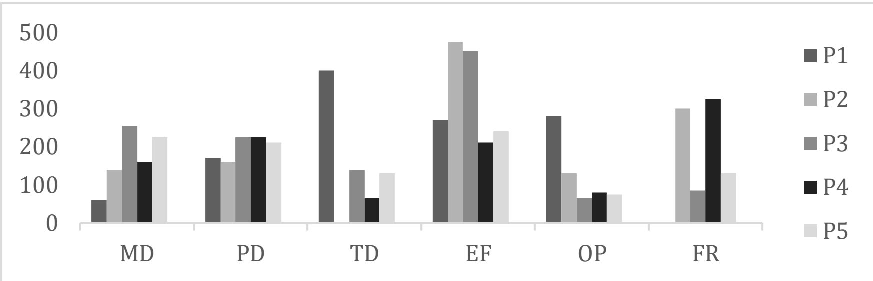

Image: Product Values of NASA-TLX Indicators

Table 2. Results of %CVL Measurement for Tofu Workers

worker	Age (yo)	Task	Product Values per Indicator						WWL	NASA-TLX	Category
			MD	PD	TD	EF	OP	FR			
P1	19	Soaking, grinding	60	170	400	270	280	0	1180	78,67	Medium
P2	43	Cooking, Filtering	140	160	0	475	130	300	1205	80,33	High
P3	35	Cooking, Filtering	255	225	140	450	65	85	1220	81,33	High
P4	24	Molding	160	225	65	210	80	325	1065	71	Medium
P5	45	Cutting	225	210	130	240	75	130	1010	67,33	Medium

Based on the calculation of the Weight Workload (WWL) for each type of task at the industry, it can be concluded that the highest mental workload is experienced by P3, who works in the Cooking and Filtering 2 process, with a WWL value of 1220. This indicates that this job has higher mental demands compared to others. Additionally, P2, who works in Cooking and Filtering 1, also has a WWL of 1205, signifying that this job also has a significant level of mental workload. Meanwhile, P1, who works in the Grinding process, has a WWL of 1180, which is still relatively high but slightly lower than the two previous roles. On the other hand, P4, who works in Molding, has a WWL of 1065, and P5, who works in Cutting, has the lowest WWL at 1010. This shows that the Molding and Cutting jobs have a lighter mental workload compared to the jobs in the Cooking and Filtering sections.

According to the mental or cognitive workload evaluation results using the NASA-TLX method, workers in the cooking and filtering processes face the highest mental stress compared to other roles. P2, working in Cooking and Filtering, achieved a NASA-TLX score of 80.33, while P3, also working in Cooking and Filtering, scored 81.33.

Both scores indicate a high level of cognitive workload. Several factors contribute to the intensity of the mental load in these tasks. Workers in this section are required to perform two tasks at once: cooking the soybeans and filtering them. Unlike other workers who focus on a single task, those in cooking and filtering need to divide their attention between two interconnected processes, which raises their cognitive workload. Moreover, the concentration and precision needed in these tasks are very high, as workers must manage both processes simultaneously. This significantly increases cognitive demands, as they must split their attention between the two related tasks (Sosnoff et al., 2014). As task complexity increases, mental workload rises, leading to shifts in brain activation patterns from left-hemispheric to bilateral (Huang et al., 2024). Cognitive control appears to moderate the relationship between task demands and physiological responses in multitasking scenarios.

Cooking must be carefully monitored to control the temperature and product quality, while filtering is done manually with simple tools, requiring physical strength and precise movements. Heat stress affects performance through thermos-physiological changes and effort exertion (Razmjou, 1996). Higher temperatures are associated with increased subjective workload scores, more intense acute subclinical health symptoms, and reduced parasympathetic nervous system activity (Lan et al., 2022). Errors at any stage could affect the product's final quality, so workers must stay focused for long periods.

Ergonomic Intervention Recommendations to Reduce Workload

Based on the analysis of physical and mental workload at the production processes in tofu industry, it was identified that improvements are necessary for the Cooking and Filtering. Workers in these areas exhibit high levels of both physical and mental workload, indicating a need for interventions to enhance worker comfort and well-being. The following are the proposed recommendations.

A potential solution for the cooking and filtering process of tofu is to design and develop a tofu filtering tool with a motorized drive. At present, workers use a manual tool. Manual filtering methods were found to be time-consuming, and causing back pain for workers (Handayani et al., 2023). The introduction of this equipment is expected to accelerate the filtering process, enabling a more efficient division of labor, with one worker focusing on cooking while another handles the filtering. This would help in reducing the overall workload. Automated filtering devices tools typically use motors and specialized materials have been developed to address these issues, reducing processing time and decreasing worker fatigue. Implementation of automated filtering machines has led to cost savings, increased production capacity, and improved worker safety through proper personal protective equipment usage (Mulyana et al., 2013). These interventions aim to reduce musculoskeletal disorders and implementing more ergonomic work processes.

A possible solution to reduce mental workload is by playing music in the production area. Hapsari et al. (2023) suggest that playing music aligned with workers' preferences can help alleviate mental stress and anxiety during work. They further explained that music has a calming effect on employees, as the rhythm helps ease mental tension, creating a more comfortable work environment. This, in turn, allows workers to focus and work more peacefully. However, the duration of the music should be managed. If played for too long, the effectiveness of the music might diminish, as workers may become less aware of it, reducing its benefits. It is recommended to play music for short intervals, about 10-15 minutes per work hour, to maintain its positive effects and ensure optimal productivity (Syafitri et al., 2022).

Physical work environments in tofu industry reveals that temperature often exceed recommended standards, potentially impacting worker comfort and productivity. These conditions can lead to increased physical and mental workload, fatigue, and reduced worker comfort. To mitigate these issues, recommendations include improving ventilation, installing coolers or blowers, providing adequate hydration, and supplying personal protective equipment (Tasyania et al., 2022).

Ergonomic interventions, such as redesigning workstations and implementing rest periods, can effectively reduce workload and associated risks. Furthermore, a workload analysis (WLA) can be performed to identify the ideal number of workers required in industrial environments (Alfonso et al., 2022; Haikal, 2024).

CONCLUSION

Based on the research findings, it can be concluded that the cooking and filtering processes at Pak Parto's small-scale tofu industry involve the highest levels of both physical and mental workload. From a physical workload perspective, the CVL analysis indicates that workers in the first cooking and filtering process have a %CVL value of 30.60% (P2) and 31.22% (P3). These values fall into the category that requires improvement in physical workload management. The prolonged manual filtering process, performed without sufficient rest breaks, significantly contributes to the high physical workload. The NASA-TLX method for mental workload assessment reveals that workers in the cooking and filtering process have a mental workload score of 80.33 (P2) and 81.33 (P3), both categorized as heavy mental workloads. The primary factors contributing to the high mental workload include multitasking in managing cooking and filtering simultaneously and the high level of precision required to maintain product quality.

To address these challenges, an improvement recommendation for tofu industry, includes implementing an automated filtering system to eliminate the need for manual filtering. Additionally, to alleviate mental workload, playing music based on workers' preferences for short durations is suggested, as it may help them relax. Improving ventilation, installing coolers or blowers, providing adequate hydration, and supplying personal protective equipment can mitigate for heat stress in tofu industry. Other studies suggest that adjusting work schedules to incorporate more rest periods and increasing the number of workers could be effective strategies. For future research, it is recommended to implement interventions based on these suggestions and compare the results before and after the interventions. Further studies could also focus on calculating the optimal number of workers and ensuring an even distribution of workload.

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